NAS8-37143
MMC-NLS-SR.001
January 1992

NASA

MARTIN MARIETTA
MANNED SPACE SYSTEMS

National Aeronautics and Space Administration
Marshall Space Flight Center
Michoud Assembly Facility

Book II - Part 2
Propulsion

# Cycle Ø(CY1991) NLS Trade Studies and Analyses Report

## FOREWORD

This document is Book II, Part 2 of the Cycle 0 Study Report containing trade studies and analyses performed by MMC in support of the Propulsion Working Group. The work was performed under NASA Contract NAS8-37143 between May 1991 and January 1992. This study was performed by Manned Space Systems, Martin Marietta Corporation, New Orleans, Louisiana for the NASA/Marshall Space Flight Center.

# INTRODUCTION

This report documents the propulsion system tasks performed in support of the NLS Cycle 0 preliminary design activities. The report includes trades and analyses covering the following subjects: 1) Maximum Tank Stretch Study; 2) No LOX Bleed Performance Analysis; 3) LOX Bleed Trade Study; 4) LO2 Tank Pressure Limits; 5) LOX Tank Pressurization System Using Helium; 6) STME Heat Exchanger Performance; 7) LH2 Passive Recirculation Performance Analysis; 8) LH2 Bleed/Recirculation Study; 9) LH2 Tank Pressure Limits; 10) LH2 Pressurization System. For each trade study an executive summary and a detailed trade study are provided. For the convenience of the reader, a separate section containing a compilation of only the executive summaries is also provided.

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# Maximum Tank Stretch Study

## 3-P-001

## Martin Marietta Manned Space Systems

## January, 1992

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## 1.0 SUMMARY

The Maximum Tank Stretch Study, 3-P-001, was performed to investigate how much an LH2 tank can realistically be stretched to achieve more performance for the 1 1/2 stage NLS vehicle. The areas examined were minimum length propulsion module (PM) concepts, manufacturing facilities impacts associated with LH2 tank stretch and potential payload performance improvements associated with a stretched tank 1 1/2 stage vehicle.

It was found that relaxation of some feedline geometry and routine constraints and utilization of different feedline flex concepts could save about 69 inches in PM length and allow a total of 11.9 ft. tank stretch (LO2 and LH2). This includes a 10.8 ft LH2 tank stretch aft. This can be accommodated by the MAF manufacturing facilities without major modifications. This can also provide a potential payload improvement of about 3000 lb for the NLS 1 1/2 stage vehicle.

Performance and configuration issues arising from this study addressed engine size and mixture ratio, PM structural arrangement, packaging, staging feedline gimballing and PM length weight sensitivities. It was concluded and recommended that these issues should be addressed in Cycle 1 studies before the benefits of a stretched tank option could be fully evaluated.

## 2.0 OBJECTIVE

The objectives of the maximum tanks stretch study, 3-P-001, are twofold.

One of the study objectives is to determine the realistic limits on how much the LH2 tank can be stretched to achieve more performance for the 1 1/2 stage NLS vehicle. It must be determined how much the Main Propulsion System (MPS) can be shortened. This translates into how much the LH2 tank can be stretched while retaining a propulsion module design concept similar to the NLS reference. The manufacturing and facilities impacts associated with stretching the LH2 tank must also be determined to define realistic stretch limits.

The second study objective is to determine the 1 1/2 stage vehicle performance impacts associated with a stretched LH2 tank. These performance impacts should assume that the LO2 tank is stretched slightly to hold engine mixture constant as the LH2 tank is stretched.

## 3.0 APPROACH

The approach taken in this study consisted of a three parallel path task flow as shown in Figure 1. One set of tasks consisted of development of a minimum length MPS concept and from that calculating parametric vehicle performance and analyzing the tank stretch potential. A second set of tasks were performed under another related contract study (3-S-008A) and consisted of development of the MAF manufacturing and facilities impacts associated with LH2 tank stretch. A third set of tasks consisted of development of a list of technical issues associated with tank stretch and sensitivity analyses of parameters such as vehicle weight and payload performance affected by these issues. The results of all three

sets of tasks were coordinated to develop conclusions relative to tank stretch and a set of recommendations for Cycle 1 were developed.

# 4.0 RESULTS

## 4.1 GROUND RULES AND ASSUMPTIONS

Certain constraints imposed by the NLS reference configuration were ground ruled for this study. These included such items as engine location, a 4/2 PM, feedline geometry and routing, prevalves and feedline disconnects similar to those baselined in the NLS reference configuration.

Assumptions were developed to minimize the MPS length given the above constraints and consistent with a Propulsion Module (PM) design similar to the NLS reference. These assumptions included that the LH2 feedline to the boosters controls minimum length MPS, minimum length contoured feedline outlets are used, 0° slope is minimum for all lines, 1.5 R/D is minimum for pipe bends and lengthy scissors ducts would not be used in feedlines to accommodate engine gimballing.

## 4.2 MINIMUM LENGTH MPS

All effort to shorten the MPS was concentrated in shortening the length (Z axis) of the LH2 booster feedline. This length controls the minimum length routing of the MPS. The baseline configuration uses scissors ducts at the engine inlets with pipe bends of R/D =2.5 and minimum line slopes of 15°. By changing the line slopes to 0° and pipe bends to R/D = 1.5, the MPS was shortened by 37 inches relative to the baseline. This reduction translates into 37 inches of potential LH2 tank stretch. Replacement of the scissors ducts with 3 pipe gimbal joints plus the 1.5 R/D bends and 0° slopes allows the MPS to be shortened 69 inches. This is the preferred concept provided motion analysis shows that adequate clearance between lines is maintained during engine gimballing.

The use of Pressure Volume Compensated (PVC) ducts was also examined for potential to shorten the MPS. PVC length is controlled by engine gimbal requirements with longer PVC ducts required for larger gimbal angles. Use of PVC ducts can reduce the MPS length by 39 to 72 inches depending on length of the PVC.

## 4.3 TANK LENGTH VS FACILITY IMPACTS

An examination of MAF manufacturing processes and facilities in study 3-S-008A revealed several facility impacts relative to the ability to stretch the LH2 tank. It was found that modifications necessary to stretch the LH2 tank up to 5 feet (NSL baseline) are minor. Facility modifications necessary to stretch the LH2 tank from 5-11 feet are considered significant but not major. To stretch a LH2 longer than 11 feet would require major modifications to existing production facilities and some new facilities. It was found that modification of certain one-of-a-kind facilities to accommodate LH2 tank stretch would be critical facility impacts. Cell A (core tank stacking) and Cell E (internal LH2 clean/iridite) are critical facilities. Cell A and Cell E have modification for tank stretch limits of 12 and 17 feet respectively. Tank stretch beyond these limits would require a new cell.

The MAF cost impacts associated with these facility impacts were studied under a company funded project. This cost study developed a cost impact vs LH2 tank stretch length that

increases in unique steps as various facilities are modified to accommodate increasing tank length.

This cost trend reflects the facility modification break points at 11 ft and 17 feet of stretch discussed above.

## 4.4 SENSITIVITY ANALYSES

Using the preferred concept to shorten the propulsion module, preliminary vehicle weight trends were developed to show the vehicle weight sensitivity to tank stretch. Tank weight increased with stretch while propulsion module weight decreased with an overall result of vehicle weight decreasing about 1134 lb /foot of tank stretch up to a stretch slightly less than 12 feet.

The payload performance of the 1 1/2 stage vehicle was examined as a function of tank stretch and was found to increase in a non-linear fashion as the tanks are stretched. It was also found that increasing the engine thrust from the NLS baseline (580 KSL) to 640 K (SL) improved performance and better utilized the stretch tank capabilities.

## 4.5 PAYLOAD PERFORMANCE

Payload performance of the 1 1/2 stage vehicle was calculated using the assumed vehicle weight trends for three LH2 tank lengths, STD ET, NLS refr (+5 ft) and + 10 ft. The length of the LO2 tank was adjusted to maintain an engine mixture ratio 6.0. Both the NLS refr STME (580K) and a 640K engine thrust level were assumed. It was found that the NLS 1 1/2 stage vehicle payload requirement of 50 Klb could be met by either a 10 ft stretched vehicle with 580K engines or a 5 ft stretched vehicle (NLS ref.) with 640K engines. Liftoff thrust/weight is marginal (1.2) for the 10 ft/580K vehicle. It appears that the NLS ref., length (5 ft stretch) with 640K engines is the better option.

## 5.0 TECHNICAL ISSUES

Technical issues that evolved from the 3-P-001 configuration and sensitivity studies can begrouped into performance issues and configuration issues.

Performance issues include: 1) Engine mixture ratio (can stretching only the LH2 tank and allowing engine mixture ratio to decrease improve stretched vehicle performance?); 2) Engine out capabilility (Can engine out requirements be lessened to eliminate the need for tank stretch?); 3) Increased engine thrust (should larger and more costly engines be used to eliminate the need for tank stretch?); 4) PM Weight vs Length is not well defined (should these analyses be refined?); and 5) 1 1/2 stage vehicle performance is extremely sensitive to PM vs length assumptions, ie, small changes in structure weight assumptions could negate an potential performance gains from increased propellant load (should structure weight assumptions be refined by more detailed design?)

Configuration issues include: 1) Boattail structural design (more detail is needed) 2) How are feedlines structure, TVC and other systems packaged in a shortened PM?; 3) Should external routing of LO2 feedlines be considered?; 4) Does the preferred 3 gimbal joint feedline concept exceed current gimbal joint technology limits?; and 5) Can the rail system used for the reference staging concept be used with a shortened boattail?

## 6.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions associated with tank stretch potential are: 1) The LH2 tank can be stretched 10-11 feet without major facility impacts; 2) The LH2 tank can be stretched 10-11 feet without a major change in the feedline concept; 3) An LH2 tank stretch of 10 feet can potentially provide a payload increase of about 3000 lb over the NASA 1 1/2 stage reference vehicle; and 4 ) Issues associated with shortened boattail structural design and packaging must be resolved to verify stretched tank performance improvements.

These conclusions do not address the issue of, "Is tank stretch the best performance improvement option for the 1 1/2 stage vehicle or are other options such as increased engine thrust worthy of consideration?"

The following recommendations relevant to stretched tanks were developed from the results of this study. Recommendations for cycle 1 study are:

1) Analyze and develop a minimum length PM concept taking into account structural arrangement, packaging, staging, MPS arrangement, and feedline gimballing limits.

2) Calculate minimum length PM mass properties and payload performance of a stretched tank/minimum length PM vehicle.

# 3-P-001 MAXIMUM TA NK STRETCH STUDY

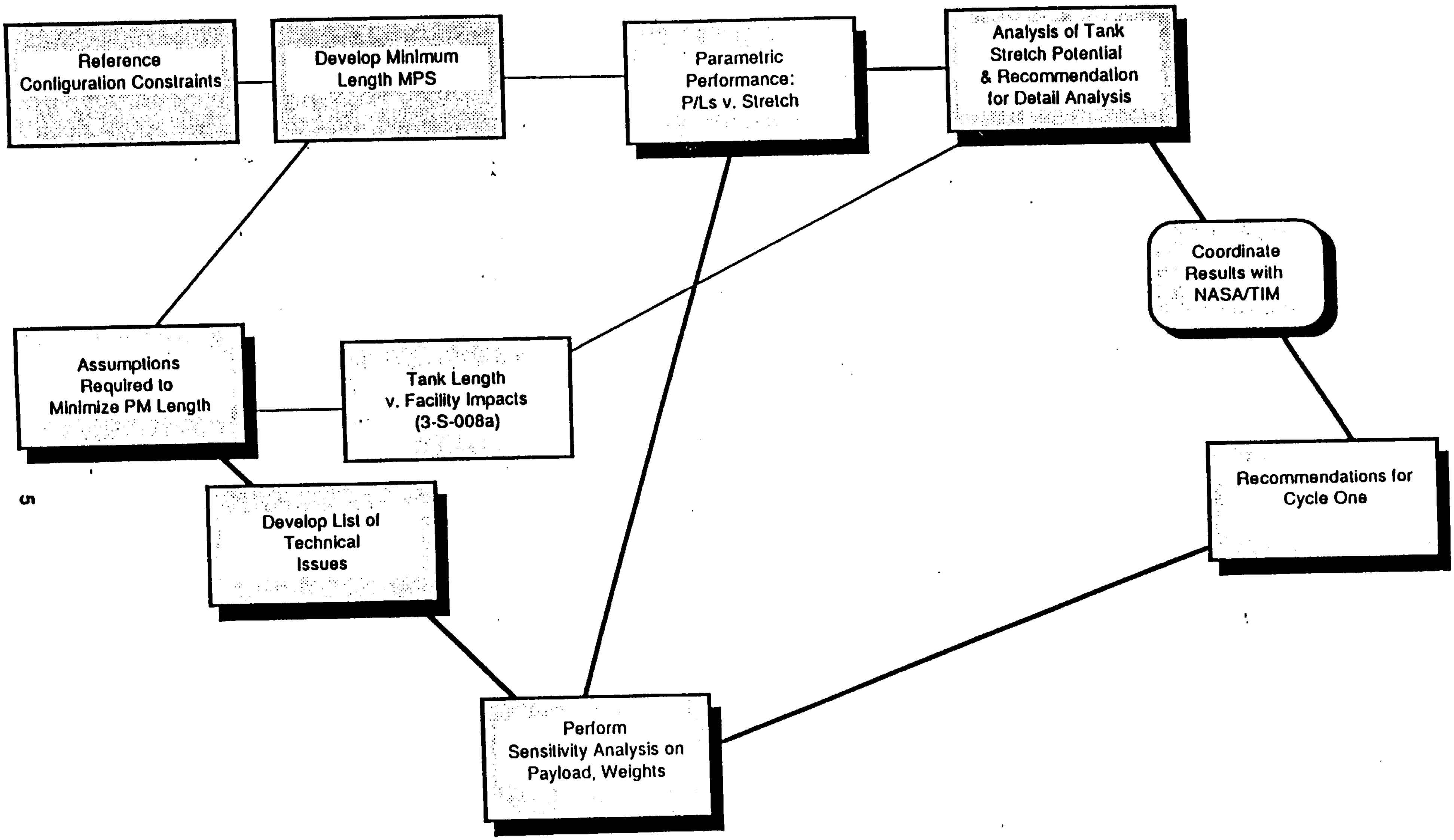


Figure 1-Task Flow

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# Task Number 3-P-018

# No LOX Bleed Performance Analysis

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20 Dec, 1991

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## Executive Summary

Task 3-P-018, "No LOX Bleed Performance Analysis" of the National Launch System Phase B study done by MMMSS under the Shuttle C Contract reads as follows, "Analysis and testing if required to assess the feasibility of no engine and/or vehicle LOX bleeds considering probable engine start condition requirements, as well as antigeyser system design." This report is based upon the Marshall Space Flight Center study plan dated August 5, 1991, and presented at the Technical Interchange Meeting at Marshall Space Flight Center on August 28, 30, 1991, by Danny Davis, the cognizant Panel Chairman. The NASA Plan presented at the August 28, 1991, TIM does not require testing.

- Upper loop performance is satisfactory - Temperature rise less than 5 F. for
- 20 inch main feedlines.
- 1 inch SOFI on downcomer.
- Zero to 1/2 inch SOFI on riser.
- 6 to 12 inch crossover duct diameter.
- Zero to 35 lb/sec topping and replenish at 163 to 180 deg R at local pressure.

- Engine feedlines likely to saturate at engine.
- Geysering may occur.
- Ambient helium bubbling will mitigate geysering effects, but will not cool LOX locally.
- Most vapor will pass through screen unless screen is flat and horizontal.
- Local pressure above saturation for engine start must be established by prepressurization. 3700 lb. tank weight impact estimated (25 psi higher tank pressure than with cold LOX).

# Task Number 3-P-018
# No LOX Bleed Performance Analysis

## 1.0 Summary

The upper loop performance is satisfactory, the temperature rise for the natural convection loop is less than 5 F. The feedlines will be near saturation at the engine inlet, and tank prepressurization will be required to 20-25 psi higher than would be required with cold LOX. This will result in a LOX tank structural weight impact of 3700 lb.

## 2.0 Problem

Analysis and testing if required to assess the feasibility of no engine and/or vehicle LOX bleeds considering probable engine start condition requirements as well as antigeyser system design.

## 3.0 Objective

General
- To evaluate the NASA reference feedline design and determine its thermal performance.

Specific
- To evaluate the NASA reference feedline design from the standpoint of geysering.
- To determine whether propellant conditions would be satisfactory for engine start.
- To identify and evaluate thermal problems and technical costs arising from the NASA reference feedline design.

## 4.0 Approach

This study was accomplished by evaluating the reference system relative to geysering, heat up from ambient, natural circulation in the upper loop, and screen performance.

## 5.0 Results

The results of this study are attached. The primary results are listed below.

## 6.0 Conclusions and Recommendations

- Upper loop performance is satisfactory. Temperature rise less than 5 F.
- Engine feedlines likely to saturate at engine. Geysering may occur. Most vapor will pass through screen if screen is not flat and horizontal.
- Local pressure above saturation for engine start must be established by prepressurization. A 3700 lb. tank weight impact is estimated.
- It is recommended that a prechill system be incorporated. See Task 3-P-019.

## 7.0 Supporting Data

- NASA-CR-64-3, "Mechanics of Geysering of Cryogenics," Martin-Marietta Aerospace Corp., 1964.

## 8.0 Attachments

Study 3-P-018 "No LOX Bleed Performance Analysis."

495149
242p

# Task Number 3-P-019

# LOX Bleed Trade Study


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## Executive Summary

Task 3-P-019 "LOX Bleed Trade Study" of the National Launch System Phase B study done by MMMSS under the Shuttle C Contract reads as follows, "Trade study to consider bleed vs. no bleed LOX system considering, at a minimum, operability, complexity, start sequence restrictions with no bleed, available propulsion module space, and tank stretch limits." This report is based upon the Marshall Space Flight Center study plan dated August 5, 1991, and presented at the Technical Interchange Meeting at Marshall Space Flight Center on August 28, 30, 1991, by Danny Davis, the cognizant Panel Chairman.

Because of the difficulty in modeling the liquid heating, it was necessary to consider the total subcooling of the liquid necessary to start the engine to come from the subcooling accomplished by the prepressurization of the tank. This was estimated to be 50 psig in an analysis submitted to NASA by MMMSS and an analysis presented to the Chief Engineer by the Propulsion Team. Therefore, this value was used as a basis of comparison for subsequent subsystem concepts.

Several subsystem concepts were considered for feedline and pump conditioning. Some of the concepts have characteristics that are obviously more desirable than others.

- Effect on LOX tank design pressure
- Predictability
- Repeatability, engine test to vehicle
- Precedence
- Impact on engine design
- Impact on engine test
- Potential for required future change
- Operational efficiency
- Hazard introduced
- Hardware complexity

The evaluation of candidate subsystems is summarized as follows.

- Reference No Bleed System cannot be expected to have subcooled propellant at engine inlets at start of prepressurization.
- Reference No Bleed System causes tank prepressurization pressure increase. A 20 psi prepressurization increase to 50 psig results in a 3700 lb. tank weight impact.
- Warm up (vapor pressure increase) after prepressurization is very slow - approximately 0.4 psi/min.
- The Onboard Bleed looks viable and eliminates the penalty due to prepressurization requirements.
- The Overboard Bleed to the facility provides good performance but at the cost of increased complexity.
- The Overboard Bleed Through the Engine to the atmosphere provides good conditions and is simple, only a bleed valve and a line to the nozzle exit are required.
- The LOX dump appears to unduly burden the engine development program unless the engine is designed for LOX lead start.

**Task Number 3-P-019**
**LOX Bleed Trade Study**

## 1.0 Summary

The reference "No Bleed" system was compared with four alternative LOX Bleed Systems. All would require an engine bleed valve, and all would allow a reduction in LOX tank prepressurization pressure and the associated 3700 lb. payload improvement compared to the "No Bleed" case.

## 2.0 Problem

"Made study to consider bleed vs. no bleed LOX system considering, at minimum, operability, complexity, start sequence restrictions with no bleed, available propulsion module space, and tank stretch limits."

## 3.0 Objective

General
To identify and evaluate alternate LOX bleed systems vs. the reference no bleed system.
Specific
To identify and evaluate alternate LOX bleed systems and determine their potential performance advantages as compared to a reference no bleed system considering the important attributes of each.

## 4.0 Approach

The approach adopted in performing this study was to consider and analyze LOX bleed systems that had previously been used and that were suggested, identify a set of attributes by which the systems could be compared, and compare the systems with the reference no bleed system.

## 5.0 Results

The results of the study are attached. The primary results are listed below.

## 6.0 Conclusions and Recommendations

- Reference No Bleed System cannot be expected to have subcooled propellant at engine inlets at start of prepressurization.
- Reference No Bleed System causes tank prepressurization pressure increase. A 20 psi prepressurization increase to 50 psig results in a 3700 lb. tank weight impact.
- Warm up (vapor pressure increase) after prepressurization is very slow - approximately 0.4 psi/min.
- The Onboard Bleed looks viable and eliminates the penalty due to prepressurization requirements.
- The Overboard Bleed to the facility provides good performance but at the cost of increased complexity.
- The Overboard Bleed Through the Engine to the atmosphere provides good conditions and is simple, only a bleed valve and a line to the nozzle exit are required.
- The LOX dump appears to unduly burden the engine development program unless the engine is designed for LOX lead start.

## 7.0 Supporting Data

Task Number 3-P-018 "No LOX Bleed Peformance Analysis."

## 8.0 Attachments

Task Number 3-P-019 "LOX Bleed Trade Study."

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# Task Number 3-P-025

# LO2 Tank Pressure Limits

Prepared By:
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## Executive Summary

NASA Statement of Work:

"Establish LO2 tank pressure limits vs. flight time considering engine start, shutdown and NPSP requirements, potential pressure stabilization of tank during max airloads, structural weight considering proof test requirements and performance."

- With no-bleed LO2 system, prepressurization will determine tank structural requirements. Current estimate of tank impact ~4500 lbm. For no impact on tank, prepress needs to be reduced to <30 psig.
- Vent valve for baseline will be sized by prelaunch operations and will have no influence on flight.
- Optimum NPSP at MECO is 30.8 psi at an ullage pressure of 20.0 psig.
- Proposed system would have a prepressurization band of 30-32 psig with relief set at 34 psig. Structural impact of ~500 lbm is largely offset by a reduction in residuals
-

## Task Number 3-P-025
## LO2 Tank Pressure Limits

### 1.0 Summary

The study has shown that the upper pressure limit will be determined by prelaunch operations. This results in a 4500 lbm increase in structural weight. This impact can be eliminated by using a bleed conditioning system and reducing the pre-pressurization level to less than 30 psig. Lower limit is determined by the saturation pressure of the liquid up to terminal drain when the engine NPSP requirement of 30.8 psi becomes important. The optimum tank pressure is ~20 psig which allows the autogenous pressurization flowrate to be reduced from the reference 3.0 lbm/sec to 2.5 lbm/sec.

### 2.0 Problem

Determine LO2 tank pressure limits for the reference configuration.

### 3.0 Objective

Determine tank and system impacts for the reference configuration.

### 4.0 Approach

The approach to performing this study was:

- Determine tank pressure vs. time for baseline trajectories.
- Use inputs from 3-P-018, 3-P-019, 3-P-017 and 3-S-010A to determine system impacts.

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## 5.0 Results

The results of this study are attached. The primary results of the study are listed below.

## 6.0 Conclusions and Recommendations

The upper limit will be sized for pre-launch operations.

Current autogenous flowrate can be reduced to lower tank pressure at MECO.

Insulated LOX tank.

Helium Inject.

Recommend 30-32 prepress band with minimum relief at 34 psig.

## 7.0 Supporting Data

## 8.0 Attachments

Study "Task Number 3-P-025, LO2 Tank Pressure Limits," dated 12/20/91.

# Task Number 3-P-026

# LOX Tank Pressurization System Using Helium

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## Executive Summary

**NASA Statement of Work:**

"Select optimum LO2 tank helium pressurization system based on tank pressure limits and specified reference trajectories and considering safety, reliability, operability, simplicity, weight, including residuals and cost."

**1.5 Stage**

- Minimum pressurization system weight is achieved using cryogenic storage helium.
- Ambient storage helium is the next best with fixed orifice autogenous being better at higher HEX temperatures.

**HLLV**

- Minimum pressurization system weight is achieved using cryogenic storage helium.
- Fixed orifice autogenous weight performance is better at higher HEX temperatures.
- Ambient helium system assumes no bottle staging and consequently will result in significant weight impact.

# Task Number 3-P-026
# LOX Tank Pressurization System Using Helium

## 1.0 Summary

A trade study was performed to evaluate LOX tank pressurization with ambient and cryogenic helium systems. A rough order of magnitude study for the autogenous pressurization system was done for comparison. Both ambient and cryogenic helium pressurization systems are lighter than an autogenous system, with the difference reducing as heat-exchanger outlet temperature is increased. The subsystem costs are significantly higher for the helium pressurization system.

## 2.0 Problem

A design concern for autogenous pressurization is that particulate ignition in the heat-exchanger discharge (pressurization supply) lines offers a catastrophic vehicle failure mode. The potential for failure increases in proportion to the selected heat exchanger discharge temperature.

## 3.0 Objective

The NASA statement of work is to "Select optimum LO2 tank helium pressurization system based on tank pressure limits and specified reference trajectories and considering safety, reliability, operability, simplicity, weight, including residuals and cost."

## 4.0 Approach

The approach was to perform an analysis of the baseline (autogenous) system varying heat exchanger outlet temperature to obtain the residual weight sensitivity. A similar analysis was performed for helium pressurization system, and design features were selected for systems at ambient and cryogenic storage. Cost and weight estimates were performed for all three systems and comparisons made.

## 5.0 Results

The system weight impact was compared by summing component and ullage weight. The payload weight impact is identical to the weight carried to orbit insertion, and increases as pressurant residuals are reduced. The autogenous system impacts payload by 4250 lbs. at the baseline conditions. The cryogenic helium storage system has a payload impact of only 3180 lbs., but at a cost increase of $1.2M/flight when compared to autogenous pressurization. An ambient helium system impacts payload by 5500 lbs., but this value can be reduced to about 4100 lbs. by staging bottles with booster engines. This system costs about $1.8M/flight more than autogenous.

## 6.0 Conclusions and Recommendations

Minimum weight is achieved using cryogenic stored helium. Ambient stored helium is the next lightest, with fixed orifice autogenous being better at higher HEX temperatures. There are more components and higher costs for the helium systems. The high-temperature GOX issue is traded with equally catastrophic bottle-failure issues.

## 7.0 Supporting Data

Task Number 3-P-017, "STME LO2 NPSP Requirements" and Task Number 3-P-025 "LO2 Tank Pressure Limits." Nein, M. E. and J. F. Thompson, "Experimental and Analytical Studies of Cryogenic Propellant Tank Pressurant Requirements, " NASA TN D3177, February 1966.

## 8.0 Attachments

Task Number 3-P-026, "LOX Tank Pressurization System Using Helium."

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# Task Number 3-P-027

# STME Heat Exchanger Performance

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## Executive Summmary

NASA Statement of Work:

Assess current STME heat exchanger performance and possible outlet temperature increase. Assuming LOX tank pressurization system uses the STME heat exchanger for an energy source, trade system performance (residuals) against engine impacts from increased heat exchanger outlet temperature.

It was shown that for the Autogenous (GOX) pressurization system, the system using ambient helium storage, or the system using cryogenic (LH2 temperature) helium storage, the heat exchanger discharge temperature should be increased above the reference 700°R. It was found that the payload improvement due to pressurization system weight saved by increasing the temperature 200°R was 600 - 1000 lb. Tank wall temperatures were increased, as a result of the 200°R pressurant temperature increase, by 130°R at cutoff. This tank wall temperature increase is not expected to be detrimental. Greater tank wall temperature increases will require further evaluation. Heat exchanger cost per flight increases were small compared to the benefit in terms of payload improvement ($8400 for 600 - 1000 lb).

The above work was based on a 1 1/2 stage vehicle. The overall effect is expected to be similar for the HLLV.

## Task Number 3-P-027
## STME Heat Exchanger Performance

### 1.0 Summary

It was shown that for the autogenous (GOX) pressurization system or the helium system the heat exchanger discharge temperature should be increased above the reference 700°R to at least 900° R. This would improve the payload capability of the vehicle by 600 - 1000 lbs.

### 2.0 Problem

To assess the value of increasing the STME heat exchanger outlet temperature.

### 3.0 Objective

General
To evaluate the desirability of increasing the STME heat exchanger outlet temperature.
Specific
To assess, for three candidate LOX tank pressurization systems, the desirability of increasing the heat exchanger outlet temperature from the reference 700°R.

### 4.0 Approach

The approach to performing this study was:
- To calculate a pressurization system weight, for 500, 700 and 900°R heat exchanger outlet temperatures, for each of three candidate LOX tank pressurization systems as follows:
  - Autogenous (GOX) pressurization system.
  - Helium system with helium stored in ambient temperature bottles.
  - Helium system with helium stored in bottles submerged in the liquid hydrogen tank.

Calculate the tank wall temperature for the 900°R tank inlet temperature to assure tank material integrity at the higher temperature.

## 5.0 Results

The results of this study are attached. The primary results of the study are listed below.

## 6.0 Conclusions and Recommendations

The payload capacity improvement due to pressurization weight saved by increasing the heat exchanger outlet temperature from 700 to 900°R was 600 - 1000 lb. The corresponding tank wall temperature increase was 130°R to 755°R. Greater tank wall temperature increases will require further evaluation. Heat exchanger cost per flight increases were small compared to the payload improvement ($8400 for 600 - 1000 lb.). Further work is required to define the helium pressurization control system.

## 7.0 Supporting Data

STPT fax NMO-086-20 "STME Heat Exchanger Parametrics" dated 10/04/91.

## 8.0 Attachments

Study "Task Number 3-P-027, STME Heat Exchanger Performance" dated 12/20/91.

# Task Number 3-P-033

# LH2 Passive Recirculation Performance Analysis

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## Executive Summary

Task 3-P-033, "LH2 Passive Recirculation Performance Analysis" of the National Launch System Phase B study done by MMMSS under the Shuttle C contact reads as follows: "Analysis of LH2 feed system with passive recirculation system to assess feasibility, margins and performance including an assessment of engine prestart restrictions if any." This is a report of this study and is based upon the Marshall Space Flight Center study plan dated August 5, 1991, and presented at the Technical Interchange Meeting at Marshall Space Flight Center on August 28, 30, 1991, by Danny Davis, the cognizant Panel Chairman.

Conclusions and recommendations were:

- Simple System.
- Screens make geysering correlation uncertain.
- Non-horizontal screens will not become vapor-bound.
- Saturated liquid hydrogen with 23 cubic inches/second of vapor being produced in pump expected after prepress.

Rapid warmup after start of prepress reduces NPSP 5 psi/min.

- Makes for short available hold time before depressurization-repressurization required.
- May force tank design pressure to be increased.
- May complicate operations by forcing very short engine start window before recycle required.
- Reevaluation required when engine start pressure requirement is established.

**Task Number 3-P-033**
**LH2 Passive Recirculation Performance Analysis**

## 1.0 Summary

The LH2 "passive recirculation" system appears to be capable of furnishing saturated, mostly liquid, hydrogen at the turbopump inlet at the start of prepressurization. The heat up rate after prepressurization of 5 psi/minute will limit hold time with tanks pressurized to 2 - 3 minutes.

## 2.0 Problem

To study and predict the performance of the reference hydrogen no bleed system.

## 3.0 Objective

General
Determine the performance of the LH2 Passive Recirculation (no-bleed) system.

Specific
Gain an understanding of the performance characteristics of the LH2 passive recirculation system. Assess geysering situation, feedline screens, and hold time.

## 4.0 Approach

The approach to performing this study was:
- Calculate engine inlet pressure with tank pressurized and unpressurized.
- Convert the engine heat flux to vapor volume.
- Calculate the rate of warmup of pump and propellant due to heating.
- Research feedline stagnation and geysering; determine performance of system relative to geysering limits.
- Calculate screen performance with regard to passing vapor.

## 5.0 Results

The results of this study are attached. The primary results are listed below.

## 6.0 Conclusions and Recommendations

- Simple System.
- Screen makes geysering correlation uncertain.
- Non-horizontal screens will not become vapor-bound.
- Saturated liquid hydrogen with 23 cubic inches/second of vapor being produced in pump expected after prepress.

Rapid warmup after start of prepress reduces NPSP 5 psi/minute.
- Makes for short available hold time before depressurization-repressurization required.
- May force tank design pressure to be increased.
- May complicate operations by forcing very short engine start window before recycle required.
- Reevaluation required when engine start pressure requirement is established.

## 7.0 Supporting Data

NASA-CR-64-3, Contract NAS8-5418, Summary Report for the Period 1 July 1963 through 30 June 1964, "Mechanics of Geysering of Cryogenics," dated June 1964.

STPT CM No. NMO-089-17, "STME Start and Shutdown Requirements," dated 10/25/91.

STPT CM No. NMO-076-05, "STME Turbopump Heat Leaks," dated 8/29/91.

## 8.0 Attachments

Task Number 3-P-033, "LH2 Passive Recirculation Performance Analysis."

# Task Number 3-P-034

# LH2 Bleed/Recirculation Study

Prepared By:
G. Platt
20 Dec, 1991

Approved By:
Z. Kirkland

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## Executive Summary

The NASA Statement of Work for this study reads as follows:

Assess a no-bleed vs. bleed or recirculation system for the LH2 feed system considering at a minimum operability, reliability, propulsion module layout and tank stretch, weight, and cost.

- Reference No-Bleed System will result in saturated LH2 in feedline and engine pump with vapor in engine pump and dry lines downstream of engine pump.
  Convection path complicated by screen.
  Analytical model and test program to anchor analytical model required.
  Warm-up after prepressurization increases saturation pressure 5 psi/minute. Would require depressurization of tank, repressurization for very short hold. (Engine start pressure not yet defined.)
- On-Board Bleed has low flowrate, hydrogen quality in turbopump will be poor (80% vapor by volume). If this is satisfactory, would allow improvement in hold after prepress relative to no-bleed system.
  Test program required.
  Slight improvement in performance compared to no bleed.
- Overboard bleed has adequate performance after prepressurization. Hold time limited due to loss of LH2 at 1.2 lb/sec per engine.
  Hardware complexity a disadvantage.
  SSME manufacturer uses this system, in principle, for single engine tests.
  Should be retained for further study.
- Backward recirculation did not appear advantageous.
  Provides good engine/pump chill.
  Introduces large volume of vapor into feedlines.
  Hardware complexity a disadvantage.

- Forward recirculation:
  Predictable, good experience with systems.
  Hardware complexity a disadvantage.
  Together with overboard bleed, provides best engine/pump chill.
  Provides best performance (best chill, no hold time limitation).

# Task Number 3-P-034
# LH2 Bleed/Recirculation Study

## 1.0 Summary

Four alternates to the reference no-bleed system were studied to establish their performance characteristics and other attributes. Forward recirculation and the overboard bleed to the facility were both superior to the reference system.

## 2.0 Problem

Assess a no-bleed vs. bleed or recirculation system for the LH2 feed system considering at a minimum operability, reliability, propulsion module layout and tank stretch, weight, and cost.

## 3.0 Objective

General
To compare candidate bleed systems with the no-bleed system for the LH2 feed system.
Specific
Compare performance, predictability, repeatability, precedence, engine impact, feed system impact, engine test impact, potential future change, operational efficiency, potential hazard, and hardware complexity of candidate bleed system concepts against the reference no-bleed system.

## 4.0 Approach

First, the candidate systems were identified and the performance of each was predicted. Then the systems were compared with each other and the reference with regard to the attributes listed in 2, above.

## 5.0 Results

The results of this study are attached. The primary results are listed below.

## 6.0 Conclusions and Recommendations

- Reference No-Bleed System will result in saturated $LH_2$ in feedline and engine pump with vapor in engine pump and dry lines downstream of engine pump.
  Convection path complicated by screen.
  Analytical model and test program to anchor analytical model required.
  Warm-up after prepressurization increases saturation pressure 5 psi/minute. Would require depressurization of tank, repressurization for very short hold.
- On-Board Bleed has low flowrate, hydrogen quality in turbopump will be poor (80% vapor by volume). If this is satisfactory, would allow improvement in hold after prepress relative to no-bleed system.
  Test program required.
  Slight improvement in performance compared to no bleed.
- Overboard bleed has adequate performance after prepressurization. Hold time limited due to loss of $LH_2$ at 1.2 lb/sec per engine.
  Hardware complexity a disadvantage.
  SSME manufacturer uses this system, in principle, for single engine tests.
  Should be retained for further study.
- Backward recirculation did not appear advantageous.
  Provides good engine/pump chill.
  Introduces large volume of vapor into feedlines.
  Hardware complexity a disadvantage.

- Forward recirculation:
  Predictable, good experience with systems.
  Hardware complexity a disadvantage
  Together with overboard bleed, provides best engine/pump chill.
  Provides best performance (best chill, no hold time limitation).

## 7.0 Supporting Data

3-P-033, "LH2 Passive Recirculation Performance Analysis."

## 8.0 Attachments

Task Number 3-P-034, LH2 Bleed/Recirculation Study "LH2 Passive Recirculation Performance Analysis."

# Task Number 3-P-038

# LH2 Tank Pressure Limits

Prepared By:
D. Vaughan
20 Dec, 1991

Approved By:
Z. Kirkland

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## Executive Summary

NASA Statement of Work:

"Establish LH2 tank pressure limits vs. flight time considering engine start and NPSP requirements, potential pressure stabilization of tank during max airloads, structural weight considering proof test requirements and performance. Also consider ascent venting criteria."

- Current autogenous flowrate results in high tank pressures that will set the vent valve relief setting at ~60 psig.
- Structural impact of ~7000 lbm due to high tank pressures. Pressure can be reduced with decreased autogenous flowrate. Proposed flowrates of 1.1 lbm/sec/booster and 0.9 lbm/sec/sustainer still results in ~1500 lbm payload impact.
- NPSP consideration indicate that the minimum ullage pressure to satisfy NPSP requirements will be ~31 psig @ MECO.
- To reduce further the structural impact an alternate pressurization system will be required, i.e., flow control valves, step orifice control.

**Task Number 3-P-038**
**LH2 Tank Pressure Limits**

## 1.0 Summary

Baseline system results in very high tank pressure during ascent. Tank impact is ~7000 lbm. This can be reduced by selecting booster and sustainer pressurization flowrates of 1.0 lbm/sec. The tank impact is then reduced to ~1500 lbm.

NPSP requirements set the lower pressure requirement at ~31 psia.

## 2.0 Problem

Assess LH2 tank pressure limits.

## 3.0 Objective

Determine tank and system impacts for the reference configuration.

## 4.0 Approach

The approach to performing this study was:
- To generate ullage pressure vs. time for the reference configuration and assess system impacts.
- Develop system to minimize impacts to the tank and still maintain adequate NPSP margin.

## 5.0 Results

The results of this study are attached. The main results of the study are listed below.

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## 6.0 Conclusions and Recommendations

The baseline autogenous flowrate of 1.4 lbm/sec results in high tank pressures that impact the tank structure by ~7000 lbm and maintain ample margin for NPSP requirements. Reduction of the autogenous flowrate to 1.0 lbm/sec reduces the impact to the tank structure to ~1500 lbm and provides adequate NPSP.

## 7.0 Supporting Data

## 8.0 Attachments

Study "Task Number 3-P-025, LO2 Tank Pressure Limits," dated 12/20/91.

# Task Number 3-P-039

# LH2 Pressurization System

20 Dec, 1991

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# Executive Summary

NASA Statement of Work:

"Select optimum LH2 tank pressurization system based on tank pressure limits and specified reference trajectories and considering safety, reliability,operability, simplicity, weight, including residuals, and cost."

Approach:

Generate baseline pressure profiles for HLLV and 1.5 Stage

Generate issues and concerns to reference

Evaluate reference with structural and NPSP requirements

Generate alternate approaches

Results:

1) Baseline fixed orifice system results in high ullage pressures during flight that have a substantial structural weight impact. NPSP requirements are only ~31 psig which results in too much margin.
2) Structural weight impact can be reduced by reduction in fixed orifice flowrate to ~1.0 lbm/sec/engine. This still results in ~1500 lbm impact due to the high ullage pressure that exists during the first portion of the flight.
3) Two approaches have been examined to reduce the initial tank pressure without impacting the NPSP requirement. These are a flow control system and a step pressurization system.
4) Assisted customer in set-up and analysis of pressurization systems.

# 3-P-039 LH2 Pressurization System

## Background

Martin Marietta Manned Space Systems was initially assigned performance of the subject contract task at the beginning of cycle 0. Early task planning was completed and preliminary analysis was done, after which the Propulsion Working Group made the decision to complete this task in-house. Martin Marietta continued to participate in the task in a review and advisory role.

This report documents the planning and analysis work performed by Martin Marietta and includes a summary of the results provided to MSFC for their completion of this task.

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# Propulsion Study Reports

## Section 2

## Complete Trade Studies and Analyses

# Maximum Tank Stretch Study

# 3-P-001

# Martin Marietta Manned Space Systems

# January, 1992


Prepared By:
R. Cronin
Contributors:
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R. Houston

Approved By:
Z. Kirkland

# TABLE OF CONTENTS

## 1.0 SUMMARY

The Maximum Tank Stretch Study, 3-P-001, was performed to investigate how much an LH2 tank can realistically be stretched to achieve more performance for the 1 1/2 stage NLS vehicle. The areas examined were minimum length propulsion module (PM) concepts, manufacturing facilities impacts associated with LH2 tank stretch and potential payload performance improvements associated with a stretched tank 1 1/2 stage vehicle.

It was found that relaxation of some feedline geometry and routine constraints and utilization of different feedline flex concepts could save about 69 inches in PM length and allow a total of 11.9 ft. tank stretch (LO2 and LH2). This includes a 10.8 ft LH2 tank stretch aft. This can be accommodated by the MAF manufacturing facilities without major modifications. This can also provide a potential payload improvement of about 3000 lb for the NLS 1 1/2 stage vehicle.

Performance and configuration issues arising from this study addressed engine size and mixture ratio, PM structural arrangement, packaging, staging feedline gimballing and PM length weight sensitivities. It was concluded and recommended that these issues should be addressed in Cycle 1 studies before the benefits of a stretched tank option could be fully evaluated.

## 2.0 OBJECTIVE

The objectives of the maximum tanks stretch study, 3-P-001, are twofold.

One of the study objectives is to determine the realistic limits on how much the LH2 tank can be stretched to achieve more performance for the 1 1/2 stage NLS vehicle. It must be determined how much the Main Propulsion System (MPS) can be shortened. This translates into how much the LH2 tank can be stretched while retaining a propulsion module design concept similar to the NLS reference. The manufacturing and facilities impacts associated with stretching the LH2 tank must also be determined to define realistic stretch limits.

The second study objective is to determine the 1 1/2 stage vehicle performance impacts associated with a stretched LH2 tank. These performance impacts should assume that the LO2 tank is stretched slightly to hold engine mixture constant as the LH2 tank is stretched.

## 3.0 APPROACH

The approach taken in this study consisted of a three parallel path task flow as shown in Figure 1. One set of tasks consisted of development of a minimum length MPS concept and from that calculating parametric vehicle performance and analyzing the tank stretch potential. A second set of tasks were performed under another related contract study (3-S-008A) and consisted of development of the MAF manufacturing and facilities impacts associated with LH2 tank stretch. A third set of tasks consisted of development of a list of technical issues associated with tank stretch and sensitivity analyses of parameters such as vehicle weight and payload performance affected by these issues. The results of all three

sets of tasks were coordinated to develop conclusions relative to tank stretch and a set of recommendations for Cycle 1 were developed.

# 4.0 RESULTS

## 4.1 GROUND RULES AND ASSUMPTIONS

Certain constraints imposed by the NLS reference configuration were ground ruled for this study. These included such items as engine location, a 4/2 PM, feedline geometry and routing, prevalves and feedline disconnects similar to those baselined in the NLS reference configuration.

Assumptions were developed to minimize the MPS length given the above constraints and consistent with a Propulsion Module (PM) design similar to the NLS reference. These assumptions included that the LH2 feedline to the boosters controls minimum length MPS, minimum length contoured feedline outlets are used, 0° slope is minimum for all lines, 1.5 R/D is minimum for pipe bends and lengthy scissors ducts would not be used in feedlines to accommodate engine gimballing.

## 4.2 MINIMUM LENGTH MPS

All effort to shorten the MPS was concentrated in shortening the length (Z axis) of the LH2 booster feedline. This length controls the minimum length routing of the MPS. The baseline configuration uses scissors ducts at the engine inlets with pipe bends of R/D =2.5 and minimum line slopes of 15°. By changing the line slopes to 0° and pipe bends to R/D = 1.5, the MPS was shortened by 37 inches relative to the baseline. This reduction translates into 37 inches of potential LH2 tank stretch. Replacement of the scissors ducts with 3 pipe gimbal joints plus the 1.5 R/D bends and 0° slopes allows the MPS to be shortened 69 inches. This is the preferred concept provided motion analysis shows that adequate clearance between lines is maintained during engine gimballing.

The use of Pressure Volume Compensated (PVC) ducts was also examined for potential to shorten the MPS. PVC length is controlled by engine gimbal requirements with longer PVC ducts required for larger gimbal angles. Use of PVC ducts can reduce the MPS length by 39 to 72 inches depending on length of the PVC.

## 4.3 TANK LENGTH VS FACILITY IMPACTS

An examination of MAF manufacturing processes and facilities in study 3-S-008A revealed several facility impacts relative to the ability to stretch the LH2 tank. It was found that modifications necessary to stretch the LH2 tank up to 5 feet (NSL baseline) are minor. Facility modifications necessary to stretch the LH2 tank from 5-11 feet are considered significant but not major. To stretch a LH2 longer than 11 feet would require major modifications to existing production facilities and some new facilities. It was found that modification of certain one-of-a-kind facilities to accommodate LH2 tank stretch would be critical facility impacts. Cell A (core tank stacking) and Cell E (internal LH2 clean/iridite) are critical facilities. Cell A and Cell E have modification for tank stretch limits of 12 and 17 feet respectively. Tank stretch beyond these limits would require a new cell.

The MAF cost impacts associated with these facility impacts were studied under a company funded project. This cost study developed a cost impact vs LH2 tank stretch length that

increases in unique steps as various facilities are modified to accommodate increasing tank length.

This cost trend reflects the facility modification break points at 11 ft and 17 feet of stretch discussed above.

## 4.4 SENSITIVITY ANALYSES

Using the preferred concept to shorten the propulsion module, preliminary vehicle weight trends were developed to show the vehicle weight sensitivity to tank stretch. Tank weight increased with stretch while propulsion module weight decreased with an overall result of vehicle weight decreasing about 1134 lb /foot of tank stretch up to a stretch slightly less than 12 feet.

The payload performance of the 1 1/2 stage vehicle was examined as a function of tank stretch and was found to increase in a non-linear fashion as the tanks are stretched. It was also found that increasing the engine thrust from the NLS baseline (580 KSL) to 640 K (SL) improved performance and better utilized the stretch tank capabilities.

## 4.5 PAYLOAD PERFORMANCE

Payload performance of the 1 1/2 stage vehicle was calculated using the assumed vehicle weight trends for three LH2 tank lengths, STD ET, NLS refr (+5 ft) and + 10 ft. The length of the LO2 tank was adjusted to maintain an engine mixture ratio 6.0. Both the NLS refr STME (580K) and a 640K engine thrust level were assumed. It was found that the NLS 1 1/2 stage vehicle payload requirement of 50 Klb could be met by either a 10 ft stretched vehicle with 580K engines or a 5 ft stretched vehicle (NLS ref.) with 640K engines. Liftoff thrust/weight is marginal (1.2) for the 10 ft/580K vehicle. It appears that the NLS ref., length (5 ft stretch) with 640K engines is the better option.

## 5.0 TECHNICAL ISSUES

Technical issues that evolved from the 3-P-001 configuration and sensitivity studies can begrouped into performance issues and configuration issues.

Performance issues include: 1) Engine mixture ratio (can stretching only the LH2 tank and allowing engine mixture ratio to decrease improve stretched vehicle performance?); 2) Engine out capabilility (Can engine out requirements be lessened to eliminate the need for tank stretch?); 3) Increased engine thrust (should larger and more costly engines be used to eliminate the need for tank stretch?); 4) PM Weight vs Length is not well defined (should these analyses be refined?); and 5) 1 1/2 stage vehicle performance is extremely sensitive to PM vs length assumptions, ie, small changes in structure weight assumptions could negate an potential performance gains from increased propellant load (should structure weight assumptions be refined by more detailed design?)

Configuration issues include: 1) Boattail structural design (more detail is needed) 2) How are feedlines structure, TVC and other systems packaged in a shortened PM?; 3) Should external routing of LO2 feedlines be considered?; 4) Does the preferred 3 gimbal joint feedline concept exceed current gimbal joint technology limits?; and 5) Can the rail system used for the reference staging concept be used with a shortened boattail?

# 6.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions associated with tank stretch potential are: 1) The LH2 tank can be stretched 10-11 feet without major facility impacts; 2) The LH2 tank can be stretched 10-11 feet without a major change in the feedline concept; 3) An LH2 tank stretch of 10 feet can potentially provide a payload increase of about 3000 lb over the NASA 1 1/2 stage reference vehicle; and 4 ) Issues associated with shortened boattail structural design and packaging must be resolved to verify stretched tank performance improvements.

These conclusions do not address the issue of, "Is tank stretch the best performance improvement option for the 1 1/2 stage vehicle or are other options such as increased engine thrust worthy of consideration?"

The following recommendations relevant to stretched tanks were developed from the results of this study. Recommendations for cycle 1 study are:

1) Analyze and develop a minimum length PM concept taking into account structural arrangement, packaging, staging, MPS arrangement, and feedline gimballing limits.

2) Calculate minimum length PM mass properties and payload performance of a stretched tank/minimum length PM vehicle.

# 3-P-001 MAXIMUM TANK STRETCH STUDY

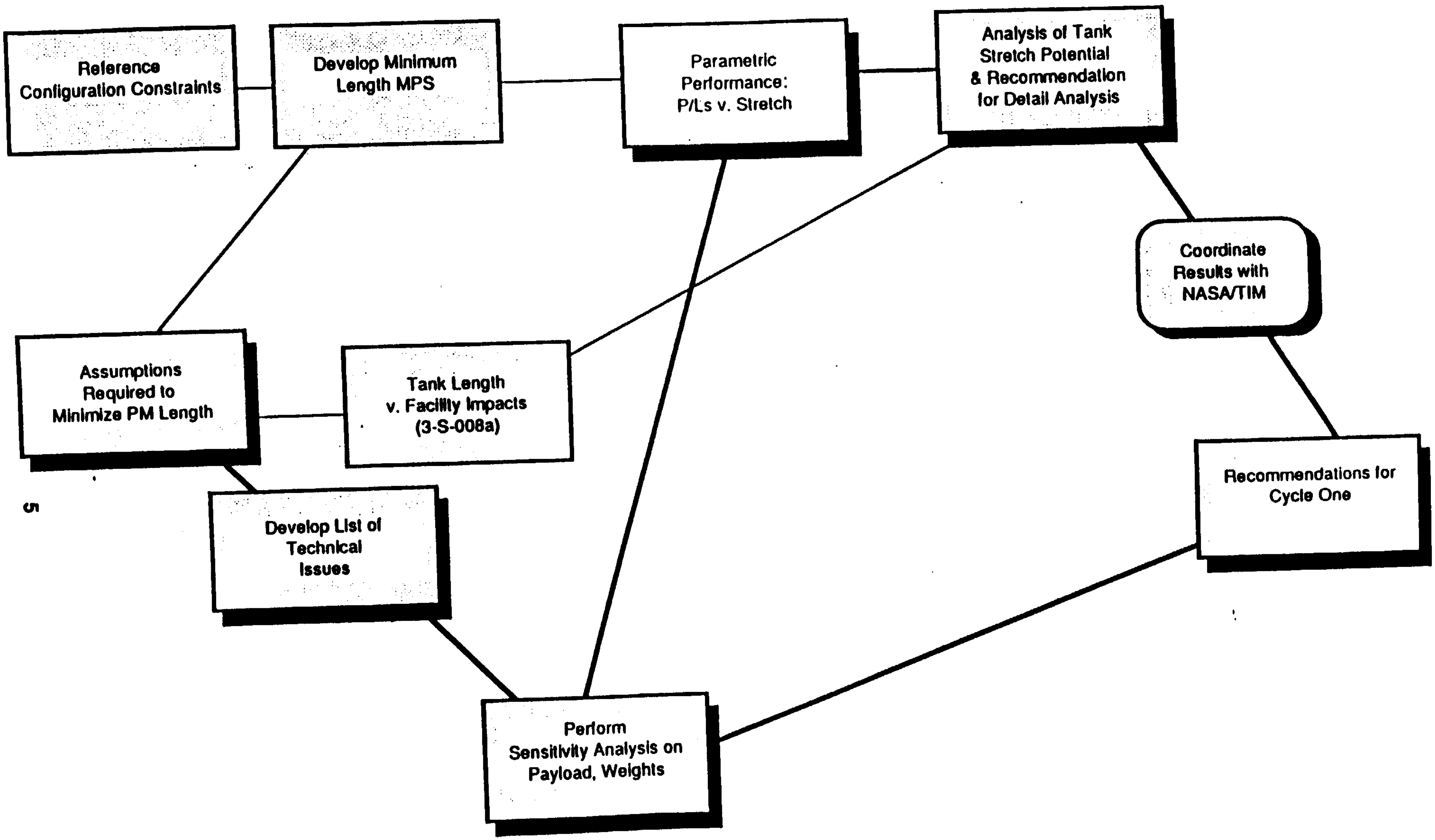


Figure 1-Task Flow

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# Maximum Tank Stretch Study

## 3-P-001

## Appendix A

## Detailed Results

# Ground Rules And Assumptions

# Reference Configuration Constraints - 3-P-001

- 4/2 Engine Configuration
- 1 Line Diameter Straight Length Before Engine Inlets
- 1 Line Diameter Prevalve
- Prevalve At Each Engine
- Vertical Disconnects
- Engine Mounting At Xt = 4383.28
- PM Feedline Routing Internal

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# Assumptions To Minimize MPS Length - 3-P-001

- LH2 Feedline To Booster Controls Minimum Length Routing
- Mimimum Length Contoured Feedline Outlets
- O° Slope Minimum On All Lines
- 1.5 R/D Minimum For Pipe Bends
- No Scissors Ducts

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# Minimum Length MPS

## Minimum Length MPS Using Scissors Joints

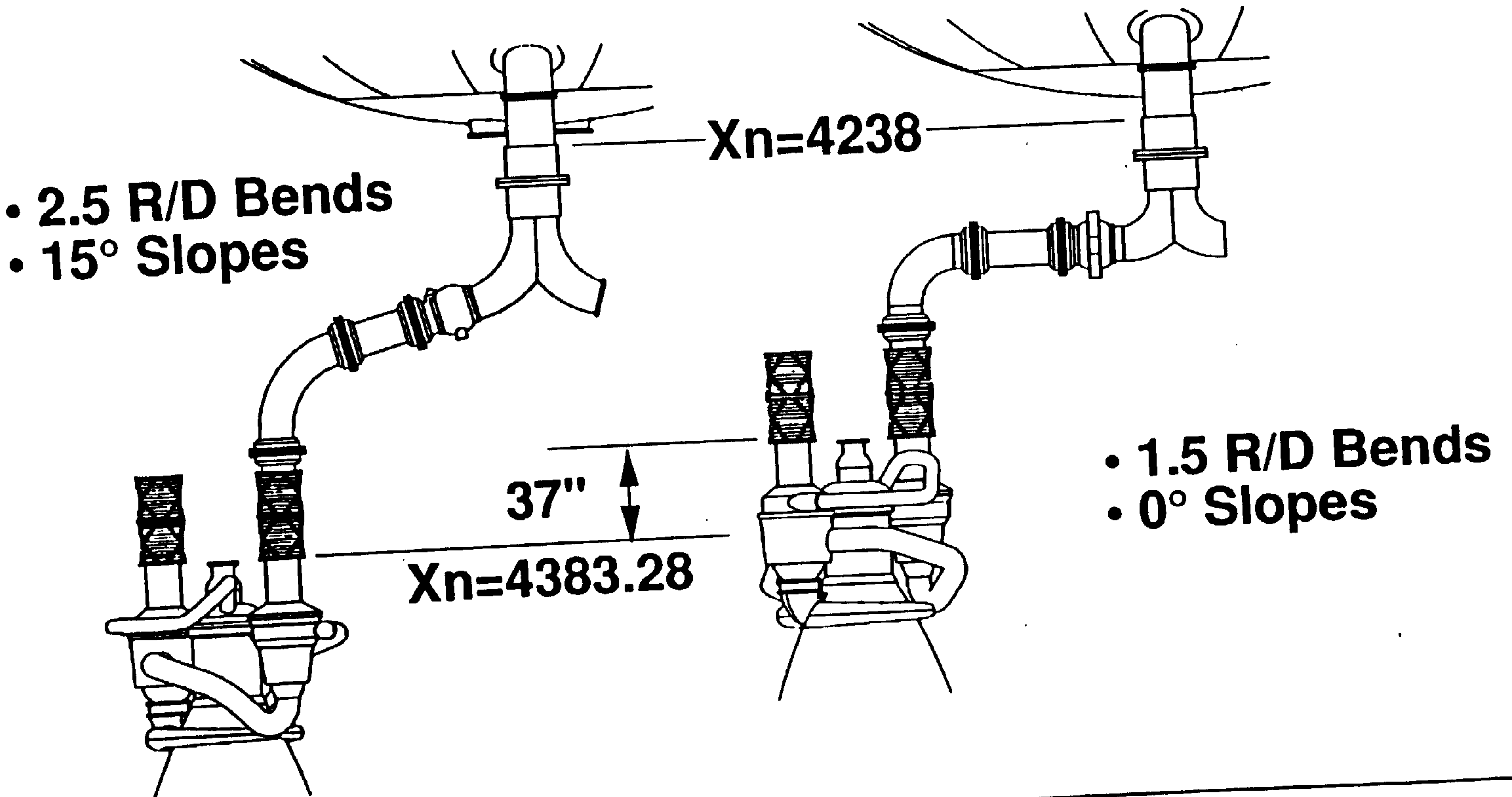
Minimum feedline routing length is controlled by the Z axis length of the booster LH2 feedlines.

The baseline LH2 sustainer feedline uses pipe bends with an R/D of 2.5, 15° minimum line slopes and scissors ducts at the engine inlets to accomodate gimballing.

Reduction of pipe bends to R/D = 1.5 and line slopes to 0° can shorten the LH2 feedline routing by 37 inches. This 37 inch reduction translates to 37 inches of potential LH2 tank stretch.

# LH2 F/L Comparison - Booster

- Baseline with Scissors & Minimum Routing




- New Groundrules Allows 37" Additional Stretch

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05.MPW.911003

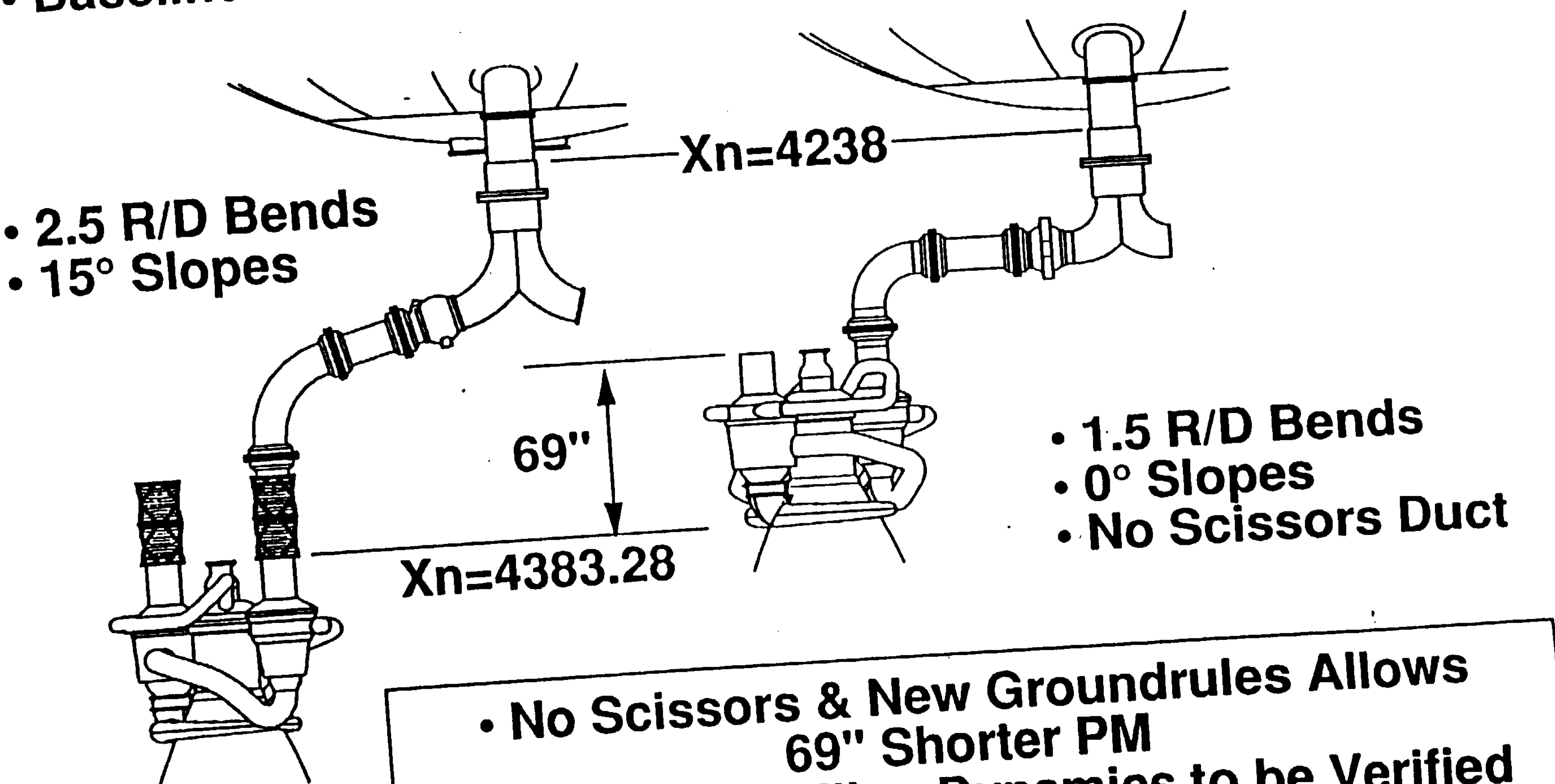
## Minimum Length MPS Using Gimbal Joints

Replacement of the scissors ducts with three pipe gimbal joints plus 1.5 R/D bends and O° slopes shortens the LH2 feedline routing length by 69 inches. This translates to a potential tank stretch of 69 inches.

Feedline movement during engine gimballing must be verified for this concept.

# LH2 F/L Comparison - Booster

- Baseline with Scissors compared to Minimum No Scissors




- No Scissors & New Groundrules Allows 69" Shorter PM
- Engine Gimballing Dynamics to be Verified

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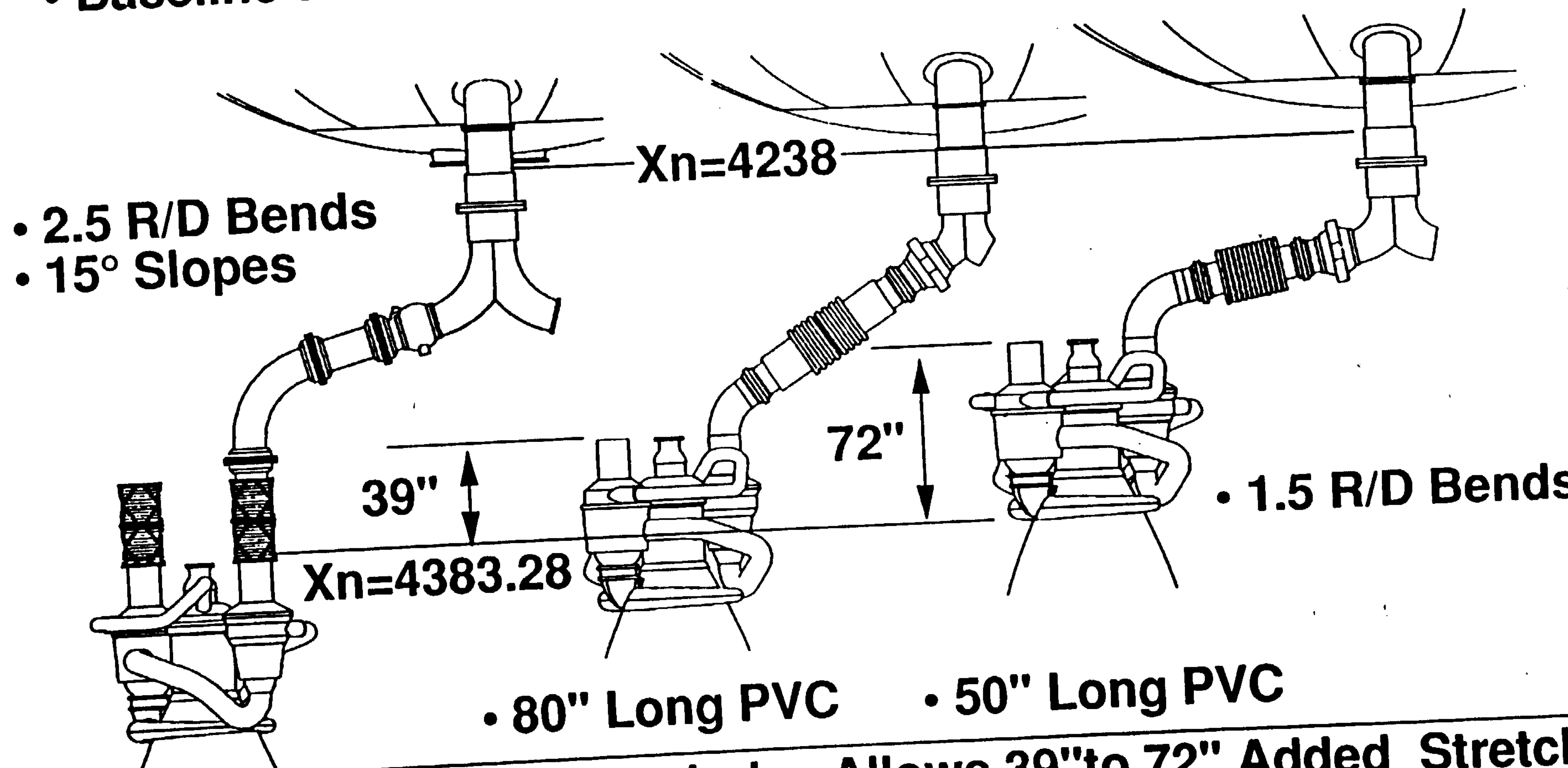
## Minimum Length MPS Using PVC Ducts

Use of Pressure Volume Compensated (PVC) ducts can reduce the LH2 feedline routing length by 39 to 72 inches depending on length of the PVC. A 50 inch PVC and bends with 1.5 R/D can shorten the feedlines and hence allow a LH2 tank stretch of 72 inches.

PVC length is controlled by engine gimbal requirements. Larger gimbal angles would mandate longer PVC ducts.

# LH2 F/L Comparison - Booster

- Baseline with Scissors compared to Minimum PVC Ducts



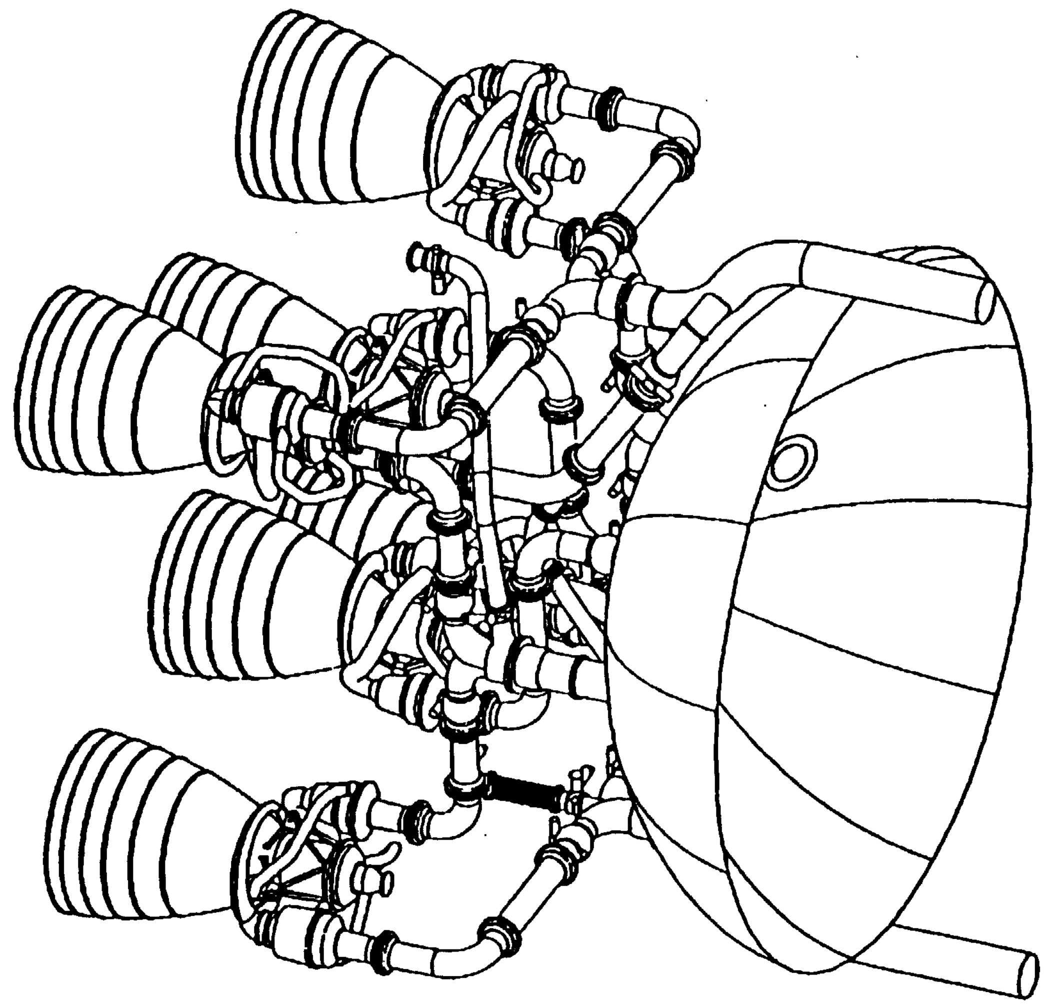

- PVC Ducts & New Groundrules Allows 39"to 72" Added Stretch
- PVC Duct Length Varies with Gimbal Requirements

## Minimum Length MPS Feedline Clearance Critical

The close proximity of lines in a shortened MPS dictates the need for a feedline motion during engine gimballing analysis.

# MPS Arrangement

- Minimum MPS Arrangement with No Scissors & 0° Slope



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# Tank Length vs Facility Impacts

## MAF Modifications For LH2 Tank Stretch

The MAF modifications necessary to stretch the LH2 tank 5 feet are considered minor.

Facility modification necessary to stretch the LH2 tank up to 11 ft. are considered to be significant but not major.

To stretch a LH2 tank longer than 11 ft. would require major modifications to existing production facilities and some new facilities.

## Summary

- Reference Configuration LH2 Tank Stretch Feasibility Re-Confirmed
  - 5 ft Stretch Requires Minor or No Modifications

- Tank Stretch up to 11 ft is Possible with Facility Modifications:
  - Cell E ~ Internal LH2 Clean & Iridite
  - Cell A ~ Core Tankage Vertical Stack
  - Cell P ~ External Clean & Prime
  - LH2 Major Weld Assy
  - LH2 Proof Test(Bldg 451)

- New Facilities/Major Mods are Required above 11 ft
  - New Proof Test Facility @ 11 ft
  - New VAB Cell A @ 12 ft
  - New VAB Cell E @ 17 ft

## Critical Facility Impacts, LH2 Tank Stretch

Modification to accomodate LH2 tank stretch of certain one-of-a-kind facilities are considered critical facility impacts

The internal LH2 clean and iridite, Cell E., can be modified to accomodate tank stretch from 5 to 17 feet. A stretch of over 17 feet would require a new cell.

For core tankage stacking, Cell A, stretch up to 12 feet can be accomodated with varying degrees of modification. A stretch of over 12 feet would require a new cell.

# Critical Facility Impacts - One-of-a-Kind Cells 3-S-008A

- Cell E - Internal LH2 Clean and Iridite

| | | |
|---|---|---|
| - Stretch | 5 ft | - Minor Tool & Facility Modification |
| - Stretch | 5 - 11 ft | - Raise Roof & Lengthen Door |
| - Stretch | 11 - 17 ft | - Raise Roof, Lengthen Door and Lower Sill |
| - Over 17 ft | | - NEW CELL |

- Cell A - Core Tankage Stack

  - 8 ft 6 in LH2 Stretch Without Major Facility Modification
  - Over 8 ft 6 in - 12 ft - Modify TPS Closeout Room
  - Over 12 ft. - NEW CELL

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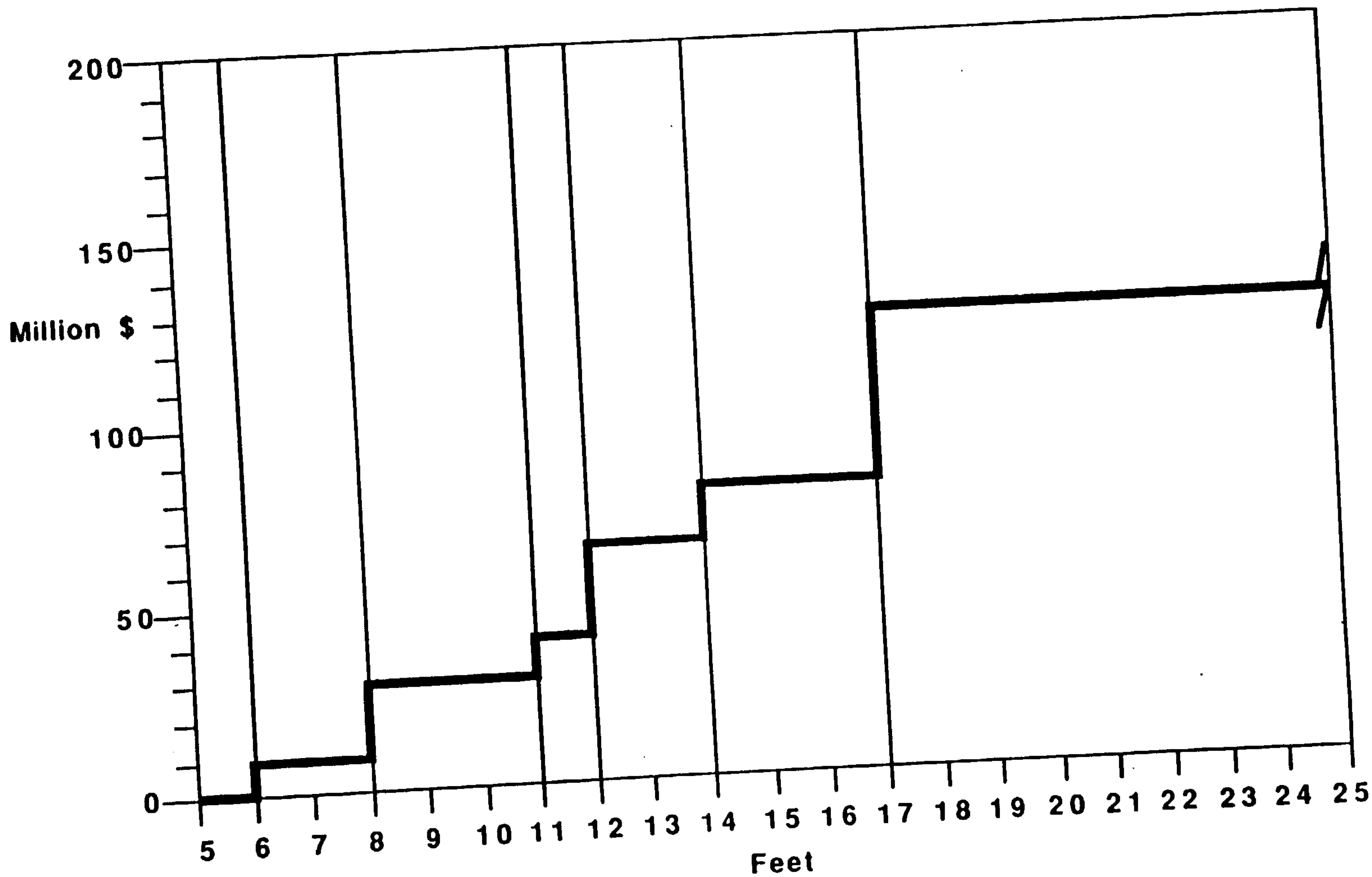
# Groundrules And Assumptions

- Delta Costs Are For Core Stage Vehicle
  - Tankage
  - Skirts
  - Propulsion Module
  - Avionics
  - IACO
- 5' Stretch Common Core Tankage Is Baseline
- Current ET Processes And Technology

# NLS Core Tankage Stretch Summary

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# Sensitivity Analyses

## Mass Properties
## Payload Performance

# Stretched NLS ROM Mass Properties - 1.5 Stage M=6.0

| Vehicle Element | Refr. - 5.0' Stretch | 11.9' Stretch |
|---|---|---|
| Titan IV Shroud | 13569 | 13569 |
| Interstage/Transition | 5563 | 5563 |
| Forward Skirt | 2603 | 2603 |
| LO2 Tank | 14061 | 14903 |
| Intertank | 12071 | 12071 |
| LH2 Tank | 36152 | 38177 |
| Aft Skirt | 3746 | 3746 |
| Auxilliary Syst./Hdw. | 13130 | 13130 |
| Avionics | 3714 | 3714 |
| Propulsion Module Incl. Engines | 107261 | 96571 |
| Total Dry Weight | 211872 | 204049 |

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## 1.5 Stage Vehicle Impacts, LH2 Tank Stretch

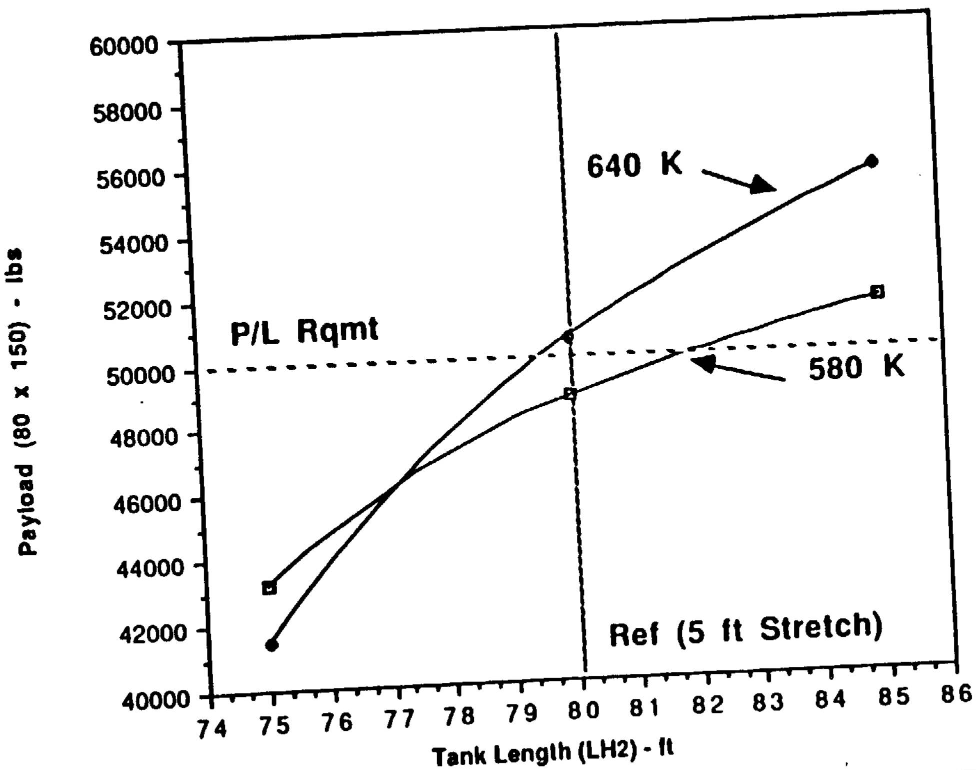
Payload capability of a 1 1/2 stage launch vehicle increases in a non-linear fashion as the tanks are stretched to accomodate more propellant.

A LH2 tank stretch of 5 feet (NLS baseline) is insufficient to meet the NLS 50 K lb, 1 1/2 stage payload requirement for this vehicle when using the baseline 580 K (SL) STME and assuming one engine out. An 8 ft. stretch will meet the P/L requirement.

Increasing STME thrust to 640 K (SL) will allow the NLS vehicle to meet the payload requirement (50 K lb) with the baselined tank size (5 ft. stretch).

# 1.5 Stage Vehicle Performance Impacts

**Objective : Impact to Payload Performance due to Engine Thrust and Tank Stretch for Sustainer Out at Liftoff**




**Ground Rules**

- 5/28/91 Ref Wts
- Mixture Ratio = 6.0
- ISP = 430.25
- 80 nm x 150 nm
- MSFC TDDP Traj

**Assumptions**

- Δ LH2 Tank Wt Estimated
- Δ LO2 Tank Wt Estimated
- Δ PM Wt Estimated
  - Staged Wt
  - Sustainer Wt
- Residuals/Reserves Adj

**1.5 Stage Vehicle Sustainer Engine Out at Liftoff Performance Can exceed 50 Klb Rqmt with 640 K STME and Addnl 5 ft Stretch**

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# Payload Performance

## 1.5 Stage Vehicle-Stretch Tank Performance

The propulsion module (boattail) was assumed to decrease in weight as its length decreased. This decrease outweighs the increase in propellant tank weight as the tanks are stretched. This overall decrease in inert weight coupled with more useable propellant produces a payload gain for a stretched vehicle.

The magnitude of the propulsion module weight vs. length characteristic must be verified by detailed structural design and analysis to ensure the payload vs stretch gains shown in this preliminary performance statement.

| | | | | | | |
|---|---|---|---|---|---|---|
| STME vacuum Thrust | | 583,400 | | | 640,000 | |
| LH2 Tank Length | Std ET (75 ft) | NLS ref (+5) | (+10) | Std ET (75 ft) | NLS ref (+5) | (+10) |
| Gross Lift Off Weight | 1,868,351 | 1,959,289 | 2,049,298 | 1,880,955 | 1,972,564 | 2,063,437 |
| Lift Off Thrust / weight | 1.332 | 1.267 | 1.208 | 1.452 | 1.380 | 1.315 |
| Used Impulse Propellant | 1,593,245 | 1,683,245 | 1,773,245 | 1,593,245 | 1,683,245 | 1,773,245 |
| MECO Weight | 193,737 | 200,218 | 205,772 | 200,818 | 208,665 | 215,776 |
| Tank weight | 73,279 | 76,156 | 79,033 | 73,279 | 76,156 | 79,033 |
| Boattail Weight retained(1) | 53,523 | 48,378 | 43,233 | 60,666 | 54,428 | 48,190 |
| Boattail weight staged(2) | 69,746 | 64,203 | 58,658 | 75,185 | 68,947 | 62,709 |
| Total Inert Weight at MECO | 125,269 | 124,534 | 123,819 | 133,945 | 130,584 | 128,948 |
| Reserves and residuals | 16,093 | 17,166 | 20,433 | 16,470 | 17,568 | 20,835 |
| Transition Section | 4,358 | 4,358 | 4,358 | 4,358 | 4,358 | 4,358 |
| Total non payload Weight | 145,720 | 146,058 | 148,610 | 154,773 | 152,510 | 154,141 |
| Gross Payload | 48,017 | 54,160 | 57,162 | 46,045 | 56,155 | 61,635 |
| Performance Margin | 4,802 | 5,416 | 5,716 | 4,605 | 5,616 | 6,164 |
| Net Payload | 43,215 | 48,744 | 51,446 | 41,441 | 50,540 | 55,472 |

Note: (1) with 2 STME's
(2) with 4 STME's
Mixture Ratio = 6.0
Isp = 430.5 seconds
Direct Inject to 80 nm by 150 nm

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# Technical Issues

# Maximum Tank Stretch - Issues



## Performance Issues

- Engine Mixture Ratio
- Engine Out Capability
- Increased Engine Thrust
- PM Weight vs. Length Not Well Defined
- 1 1/2 Stage Vehicle Performance Extremely Sensitive To PM Weight vs. Length Assumptions, ie, Small Changes In Structure Weight Assumptions Could Negate Any Potential Performance Gains From Increased Propellant Load

# Maximum Tank Stretch - Issues

3-P-001

## Configuration Issues

- Boattail Structural Design
- Packaging In PM - Feedlines, Structure, TVC, Other Subsystems
- External Routing Of Feedlines
- Feedline Gimbal Joint Technology Limits
- Can Rail System Work With Short Boattail For Reference Staging Concept

# Conclusions and Recommendations

# Maximum Tank Stretch - Conclusions



- LH2 Tank Can Be Stretched Aft 10-11 Ft Without Major Facility Impacts
- LH2 Tank Can Be Stretched Aft 10-11 Ft. Without Major Change In Feedline Concept
- A LH2 Tank Stretch Of 10 Ft. Can Potentially Provide A Payload Increase Of About 3000 Lb. Over The NASA 1.5 Stage Reference Vehicle
- Issues Associated With Shortened Boattail Structural Design And Packaging Must Be Resolved To Verify Stretched Tank Performance Improvements

# Recommendations For Cycle 1

- Using The Revised NLS Cycle 1 Propulsion Module Reference Configuration

- Cycle 1 Recommendations Relevent To Stretched Tanks
  - Re-Confirm Minimum MPS Length Using Cycle O Ground Rules
  - Develop Minimum Length PM Structural Arrangement
  - Develop Subsystem (TVC, Avionics, Pneumatic) Packaging For Minimum Length PM
  - Develop Staging Concept Details For Minimum Length PM And Analyze
  - Develop MPS Arrangement (Internal vs. External LO2 Feedlines For Minimum Length PM
  - Analyze Feedline Movement During Engine Gimballing (Develop Feedline Gimbal Requirements)
  - Develop Minimum Length Propulsion Module Mass Properties
  - Calculate Payload Performance Of Stretched Tank/Minimum Length PM Vehicle

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# Task Number 3-P-018

# No LOX Bleed Performance Analysis

Prepared By:
G. Platt
20 Dec, 1991

Approved By:
Z. Kirkland

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## Executive Summary

Task 3-P-018, "No LOX Bleed Performance Analysis" of the National Launch System Phase B study done by MMMSS under the Shuttle C Contract reads as follows, "Analysis and testing if required to assess the feasibility of no engine and/or vehicle LOX bleeds considering probable engine start condition requirements, as well as antigeyser system design." This report is based upon the Marshall Space Flight Center study plan dated August 5, 1991, and presented at the Technical Interchange Meeting at Marshall Space Flight Center on August 28, 30, 1991, by Danny Davis, the cognizant Panel Chairman. The NASA Plan presented at the August 28, 1991, TIM does not require testing.

- Upper loop performance is satisfactory - Temperature rise less than 5 F. for
- 20 inch main feedlines.
- 1 inch SOFI on downcomer.
- Zero to 1/2 inch SOFI on riser.
- 6 to 12 inch crossover duct diameter.
- Zero to 35 lb/sec topping and replenish at 163 to 180 deg R at local pressure.

- Engine feedlines likely to saturate at engine.
- Geysering may occur.
- Ambient helium bubbling will mitigate geysering effects, but will not cool LOX locally.
- Most vapor will pass through screen unless screen is flat and horizontal.
- Local pressure above saturation for engine start must be established by prepressurization.
3700 lb. tank weight impact estimated (25 psi higher tank pressure than with cold LOX).

## Task Number 3-P-018
## No LOX Bleed Performance Analysis

### 1.0 Summary

The upper loop performance is satisfactory, the temperature rise for the natural convection loop is less than 5 F. The feedlines will be near saturation at the engine inlet, and tank prepressurization will be required to 20-25 psi higher than would be required with cold LOX. This will result in a LOX tank structural weight impact of 3700 lb.

### 2.0 Problem

Analysis and testing if required to assess the feasibility of no engine and/or vehicle LOX bleeds considering probable engine start condition requirements as well as antigeyser system design.

### 3.0 Objective

General
- To evaluate the NASA reference feedline design and determine its thermal performance.

Specific
- To evaluate the NASA reference feedline design from the standpoint of geysering.
- To determine whether propellant conditions would be satisfactory for engine start.
- To identify and evaluate thermal problems and technical costs arising from the NASA reference feedline design.

### 4.0 Approach

This study was accomplished by evaluating the reference system relative to geysering, heat up from ambient, natural circulation in the upper loop, and screen performance.

## 5.0 Results

The results of this study are attached. The primary results are listed below.

## 6.0 Conclusions and Recommendations

- Upper loop performance is satisfactory. Temperature rise less than 5 F.
- Engine feedlines likely to saturate at engine. Geysering may occur. Most vapor will pass through screen if screen is not flat and horizontal.
- Local pressure above saturation for engine start must be established by prepressurization. A 3700 lb. tank weight impact is estimated.
- It is recommended that a prechill system be incorporated. See Task 3-P-019.

## 7.0 Supporting Data

- NASA-CR-64-3, "Mechanics of Geysering of Cryogenics," Martin-Marietta Aerospace Corp., 1964.

## 8.0 Attachments

Study 3-P-018 "No LOX Bleed Performance Analysis."

# Task Number 3-P-018

# No LOX Bleed Performance Analysis

## Attachment-Detailed Data

C-2

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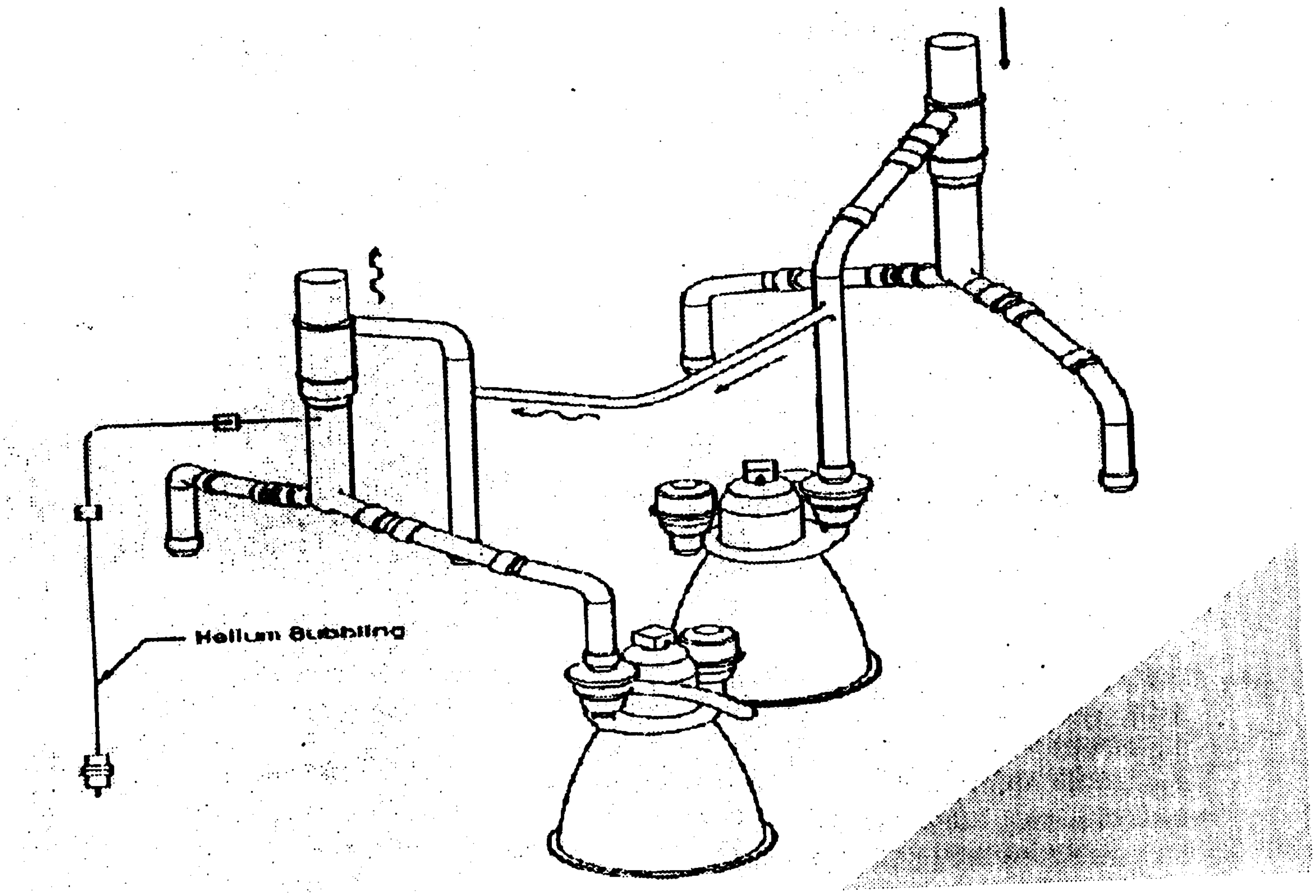
The problem of liquid oxygen feedline and engine conditioning during prelaunch is composed of several parts, including loading, prevention of geysering when the feedline is full and when there is liquid oxygen in the propellant tank, predicting and/or promoting convection in the feedline, predicting the behavior of feedline screens (if used) , predicting the heat transfer to the LOX system within the engine, devising design solutions to provide adequate engine and feedline conditioning, and appraising and comparing the conceived solution for selection and adoption.

NASA presented a reference configuration for the feedlines, shown on the facing page, which showed large, approximately 20 inch diameter feedlines which are interconnected at their lower ends by a line to permit circulation between the feedlines and to allow the LOX from both lines to be utilized in case of loss of one of the two sustainer engines. Each of these feedlines would feed three engines during boost for the 1-1/2 stage vehicle or two engines for the HLLV vehicle. For the 1-1/2 stage vehicle, four engines would be jettisoned at staging, two from each side. The HLLV vehicle would not jettison any of its four liquid propellant engines.

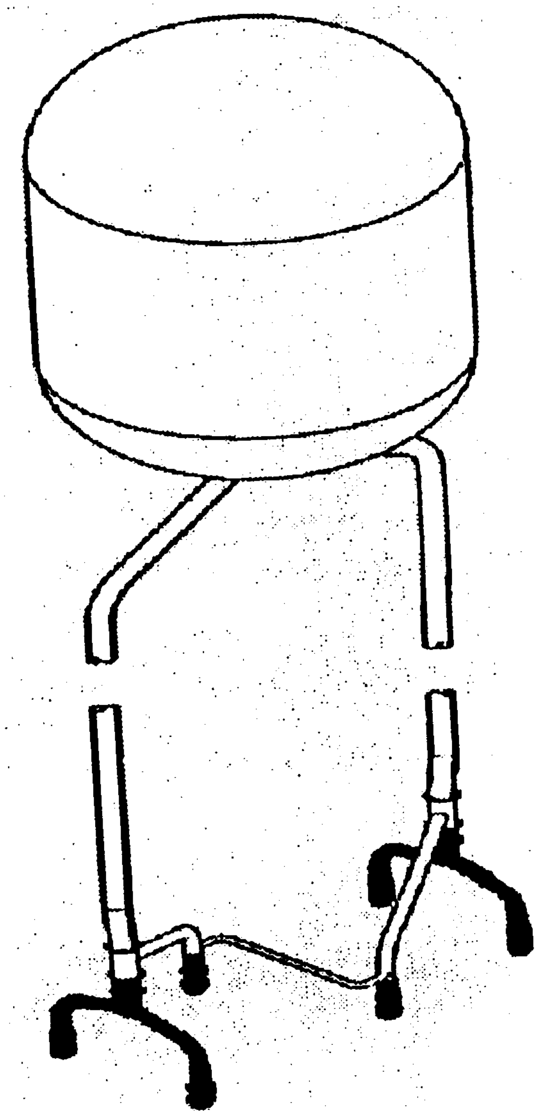
# NASA Reference Configuration



## Upper Loop

It was logical to divide the feed system into two parts for analysis. The upper loop would comprise the tank, the two 20 inch feedlines and the crossover line. The other part would be each individual engine feedline. There were several analyses of the upper loop, one by NASA, and three by MMMSS. In Huntsville, the analysis was done by calculating the heat leak to each 20 inch feedline, assuming one inch of foam on one line and the other line bare. The foam insulated line would then act as a downcomer and the bare line as a riser.

The loop flowrate was calculated to be 93 lb/sec for zero replenish, 100 lb/sec for the calculated replenish heat leak, and 145 lb/sec for 10 times the calculated replenish heat leak. The flow loop temperature rise was calculated to be 4.0, 4.6, and 9.3 deg F for the three cases. The calculation was also done by both Martin-Denver and Martin-Michoud. With different assumptions for the replenish flow and heat leaks for the tank and riser lines and engines using the Flow II model, all analyses show similar satisfactory system performance.



**UPPER LOOP**
**(Tank Bottom to Crossover)**
**Good Performance, No Problem Found**

- Crossover Flowrate 85-100 lb/sec
- Flow Loop Temperature Rise < 5 F

- Variables:
  - Feedline Insulation
    1 inch on Downcomer
    None to 1/2 inch on Riser
  - Riser and Downcomer Diameter 20 inches
  - Engine Heat Leak 2 to 10 btu/sec/engine
  - Topping/Replenish Flowrate
    0 to 35 lb/sec
    at
    163 to 180deg R
  - Crossover Diameter 6 - 12 inches

3-P-018
Page 2

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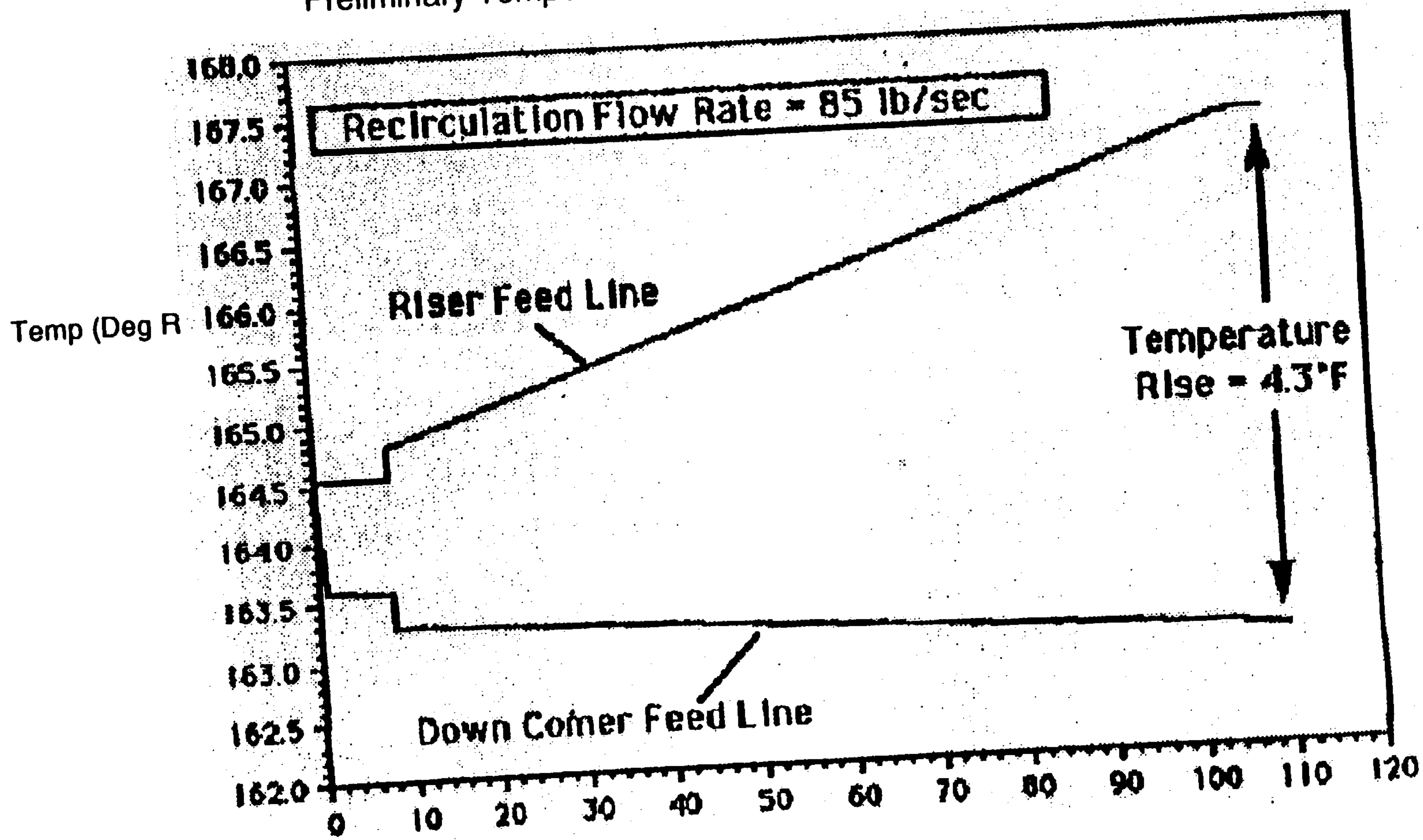
A plot from one of the Denver calculations is shown on the facing page. From these analyses it is concluded that the natural convection loop will condition the upper loop satisfactorily.

# Nominal LO2 Feed System Temperatures

Preliminary Temperature Profile in LO2 Main Feedline

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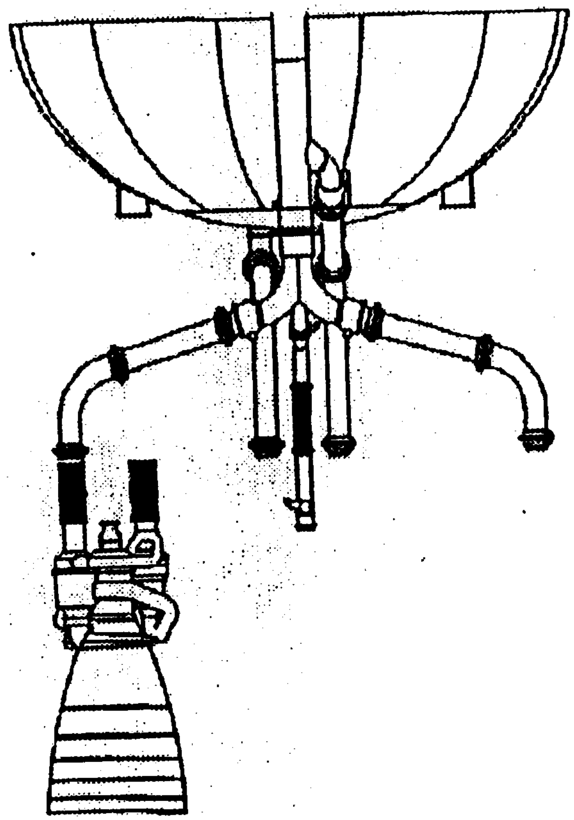
## Feedline Conditioning

The feedlines were analyzed separately. The length to diameter ratio of each feedline was, for the reference configuration, in the range of 10 to 20. Since the reference configuration is not the final configuration, they may eventually have L/D ratios even higher. The likelihood of stagnation, leading, possibly, to geysering may be evaluated by reference to the next page which shows the results of a large number of geysering tests done under contract to NASA by Martin Marietta. The indication from this figure is that geysering should not happen for a 12 inch line, however, for a smaller line or a longer line, it may well be in the geysering region. Calculations show that a 10 inch line 20 feet long would be in the geysering region. Also, it is considered mandatory to have a feedline screen similar to that of the Shuttle Orbiter. It is not known how this screen will affect the convective pattern within the line. Attempts to model the convection within the line including screen effects have not yet been successful.



## Feedlines Reference No Bleed

- Rule of Thumb
  L/D < 10 Convection OK
  L/D > 20 Convection Not Enough (Geyser Region)

- Probable Design Between These or Even L/D > 20
  - Screen In Line Will Inhibit Convection - Pores in Shuttle-Type Screen Will Be "Stable"
  - Most Vapor Will Pass Through and Rise Through Feedline if Screen is not Flat, Horizontal
  - Feedline may be Saturated or not have Repeatable Peformance
  - Analytical Models have not been Confirmed
  - Helium Bubbling, If Used, Will Not Result In Evaporative Cooling at Engine Inlet (Assumes Ambient Helium)
  - Possible Design Solutions
    On Board Bleed
    Overboard Bleed



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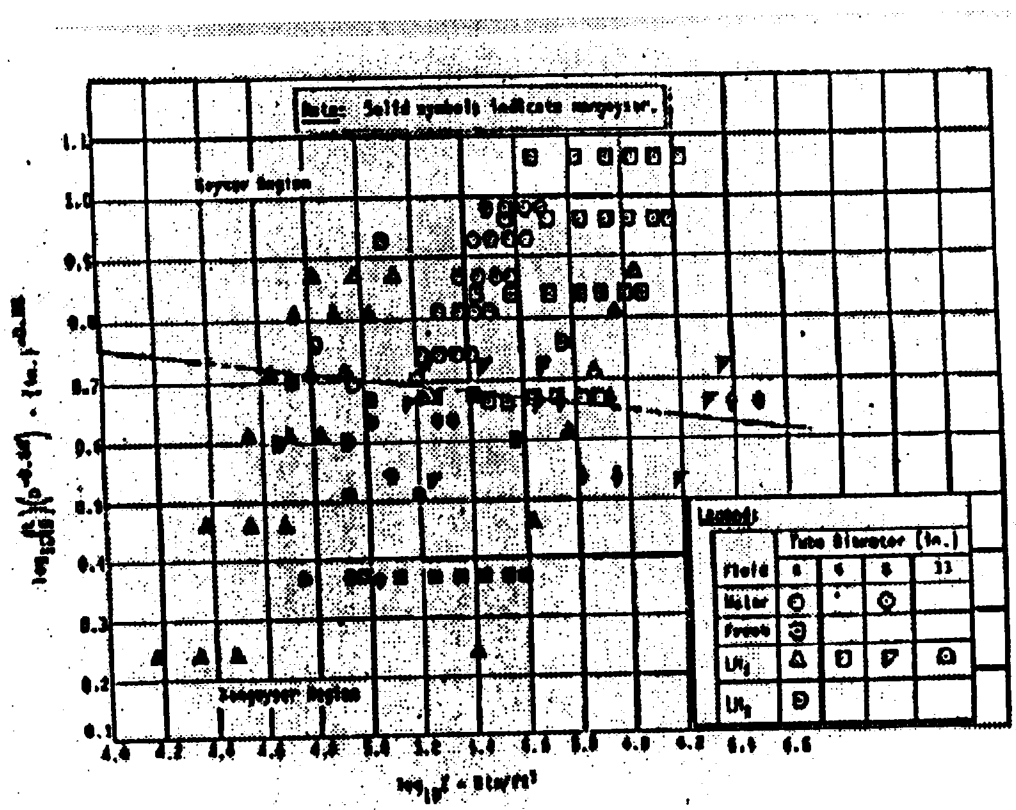

| | L = 20' - 240" | | |
|---|---|---|---|
| | 8" | 10" | 12" |
| $(\frac{L}{D} \cdot D^{-.68})$ | 7.3 | 5.02 | 3.7 |
| $\log_{10}(\frac{L}{D} \cdot D^{-.68})$ | .86 | .7 | .568 |

$q/A = 60\ B/Hr\text{-}ft^2$

| | LOX | $LH_2$ |
|---|---|---|
| | $Z = 1990 \cdot L$ | $768 \cdot L$ |
| L = 20 | $Z = 477600$ | 184320 |
| $\log_{10}$ | $Z = 5.67$ | 5.26 |

$$Z = \frac{(q/A) \cdot L}{12 \propto (N_{PR})^{1/3}}$$



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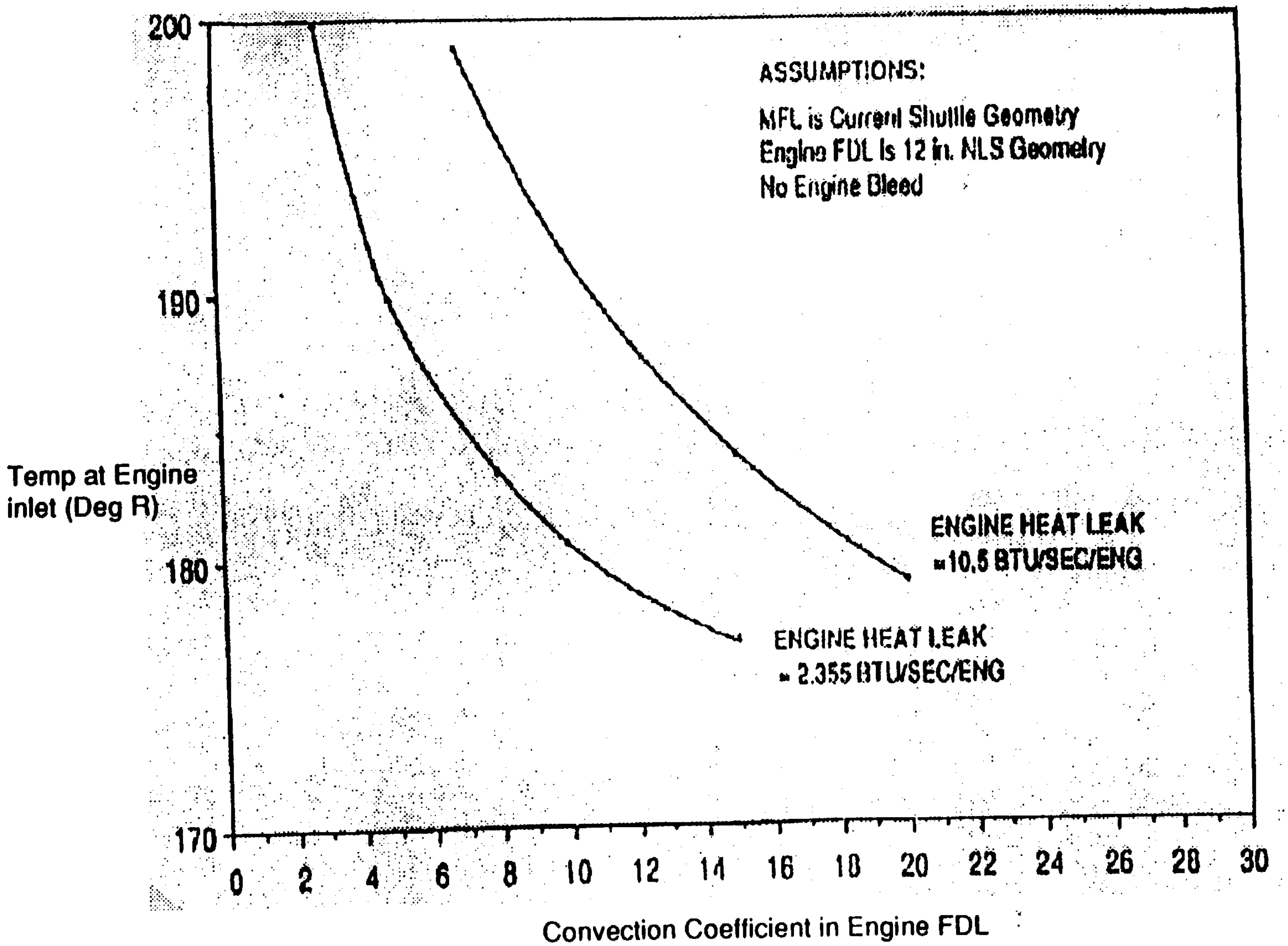
## Assumptions

- MFL Flow Loop Temperature = 165 Deg R
- EFL Heat Leak Same as Orbiter Feedlines With SOFI
- No Flow in Engine Feedlines

## Discussion of Math Model Predictions

- Engine Inlet Temperatures Strongly Influenced by Convection Coefficient
- "Best" Convection Coefficient (Based on Best Match Between Predicted and Measured Temperatures for Orbiter Feedlines During 1978 Denver EPL Tests)
- Convection Coefficient of 10 or 15 Gives Best Match When Flow and/or Helium Inject Flow Present
- Convection Coefficient of 5 Gives Best Match When No Flow and Helium Inject Present

# NLS Engine Inlet Temperature With No Engine Bleed



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## No LOX Bleed
## Summary & Conclusions

- Upper loop performance is satisfactory - Temperature rise less than 5 F. for
- 20 inch main feedlines.
- 1 inch SOFI on downcomer.
- Zero to 1/2 inch SOFI on riser.
- 6 to 12 inch crossover duct diameter.
- Zero to 35 lb/sec topping and replenish at 163 to 180°R. at local pressure.

- Engine feedlines likely to saturate at engine.
- Geysering may occur.
- Ambient helium bubbling will mitigate geysering effects, but will not cool LOX locally.
- Most vapor will pass through screen unless screen is flat and horizontal.
- Local pressure above saturation for engine start must be established by pre pressurization.

3700 lb. tank weight impact estimated (25 psi higher tank pressure than with cold LOX).

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# Task Number 3-P-019

# LOX Bleed Trade Study

Prepared By:
G. Platt
20 Dec, 1991

Approved By:
Z. Kirkland

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## Executive Summary

Task 3-P-019 "LOX Bleed Trade Study" of the National Launch System Phase B study done by MMMSS under the Shuttle C Contract reads as follows, "Trade study to consider bleed vs. no bleed LOX system considering, at a minimum, operability, complexity, start sequence restrictions with no bleed, available propulsion module space, and tank stretch limits." This report is based upon the Marshall Space Flight Center study plan dated August 5, 1991, and presented at the Technical Interchange Meeting at Marshall Space Flight Center on August 28, 30, 1991, by Danny Davis, the cognizant Panel Chairman.

Because of the difficulty in modeling the liquid heating, it was necessary to consider the total subcooling of the liquid necessary to start the engine to come from the subcooling accomplished by the prepressurization of the tank. This was estimated to be 50 psig in an analysis submitted to NASA by MMMSS and an analysis presented to the Chief Engineer by the Propulsion Team. Therefore, this value was used as a basis of comparison for subsequent subsystem concepts.

Several subsystem concepts were considered for feedline and pump conditioning. Some of the concepts have characteristics that are obviously more desirable than others.

- Effect on LOX tank design pressure
- Predictability
- Repeatability, engine test to vehicle
- Precedence
- Impact on engine design
- Impact on engine test
- Potential for required future change
- Operational efficiency
- Hazard introduced
- Hardware complexity

The evaluation of candidate subsystems is summarized as follows.

- Reference No Bleed System cannot be expected to have subcooled propellant at engine
inlets at start of prepressurization.
- Reference No Bleed System causes tank prepressurization pressure increase.
A 20 psi prepressurization increase to 50 psig results in a 3700 lb. tank weight impact.
- Warm up (vapor pressure increase) after prepressurization is very slow - approximately 0.4 psi/min.
- The Onboard Bleed looks viable and eliminates the penalty due to prepressurization requirements.
- The Overboard Bleed to the facility provides good performance but at the cost of increased complexity.
- The Overboard Bleed Through the Engine to the atmosphere provides good conditions and is
- The Overboard Bleed Through the Engine to the nozzle exit are required.
simple, only a bleed valve and a line to the nozzle exit are required.
- The LOX dump appears to unduly burden the engine development program unless the engine
is designed for LOX lead start.

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**Task Number 3-P-019**
**LOX Bleed Trade Study**

## 1.0 Summary

The reference "No Bleed" system was compared with four alternative LOX Bleed Systems. All would require an engine bleed valve, and all would allow a reduction in LOX tank prepressurization pressure and the associated 3700 lb. payload improvement compared to the "No Bleed" case.

## 2.0 Problem

"Made study to consider bleed vs. no bleed LOX system considering, at minimum, operability, complexity, start sequence restrictions with no bleed, available propulsion module space, and tank stretch limits."

## 3.0 Objective

General
To identify and evaluate alternate LOX bleed systems vs. the reference no bleed system.
Specific
To identify and evaluate alternate LOX bleed systems and determine their potential performance advantages as compared to a reference no bleed system considering the important attributes of each.

## 4.0 Approach

The approach adopted in performing this study was to consider and analyze LOX bleed systems that had previously been used and that were suggested, identify a set of attributes by which the systems could be compared, and compare the systems with the reference no bleed system.

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## 5.0 Results

The results of the study are attached. The primary results are listed below.

## 6.0 Conclusions and Recommendations

- Reference No Bleed System cannot be expected to have subcooled propellant at engine inlets at start of prepressurization.
- Reference No Bleed System causes tank prepressurization pressure increase. A 20 psi prepressurization increase to 50 psig results in a 3700 lb. tank weight impact.
- Warm up (vapor pressure increase) after prepressurization is very slow - approximately 0.4 psi/min.
- The Onboard Bleed looks viable and eliminates the penalty due to prepressurization requirements.
- The Overboard Bleed to the facility provides good performance but at the cost of increased complexity.
- The Overboard Bleed Through the Engine to the atmosphere provides good conditions and is simple, only a bleed valve and a line to the nozzle exit are required.
- The LOX dump appears to unduly burden the engine development program unless the engine is designed for LOX lead start.

## 7.0 Supporting Data

Task Number 3-P-018 "No LOX Bleed Peformance Analysis."

## 8.0 Attachments

Task Number 3-P-019 "LOX Bleed Trade Study."

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# Task Number 3-P-019

# LOX Bleed Trade Study

# Attachment-Detailed Data

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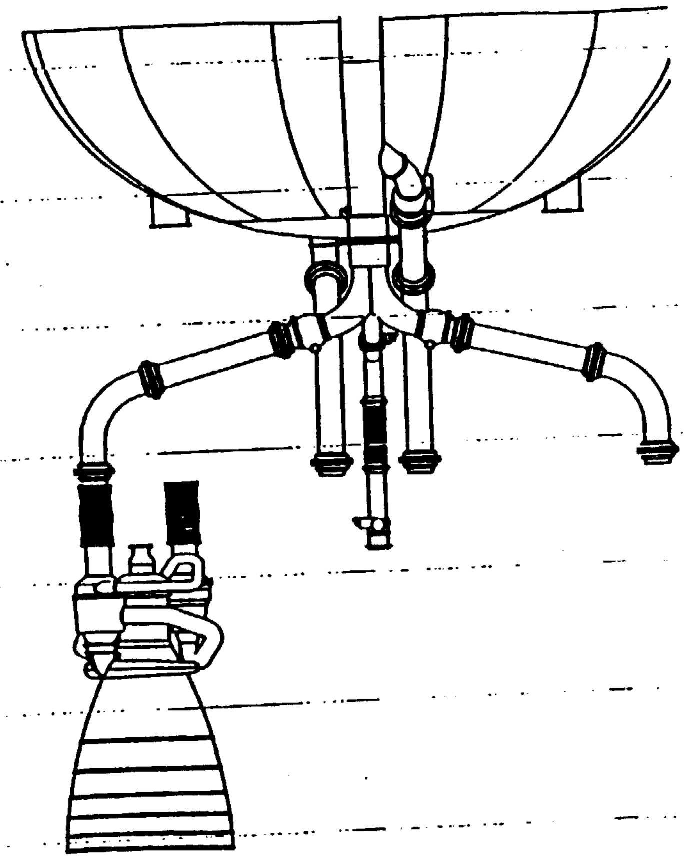
The reference No-Bleed system is evaluated in Task Number 3-P-018.

Because of difficulty in modeling the liquid heating in the feedline and because of the potential of having saturated liquid at the pump inlet at the time of prepressurization, it was necessary to consider the total subcooling of the liquid necessary to start the engine to come from the subcooling accomplished by the prepressurization of the tank. This was estimated to be 50 psig in an analysis submitted to NASA by MMMSS and an analysis presented to the Chief Engineer by the Propulsion Team. Therefore, this value was used as a basis of comparison for subsequent subsystem concepts which permit calculation of LOX temperature at the pump inlet and within the pump. A 50 psig prepressurization would result in a tank design pressure increase, compared to the reference tank design, of 20 psi. This would result in a 3700 lb. tank weight penalty.

## Feedlines Reference No Bleed



- Rule of Thumb
  L/D < 10 Convection OK
  L/D > 20 Convection Not Enough (Geyser Region)

- Probable Design Between These or Even L/D > 20
  - Screen In Line Will Inhibit Convection - Pores In Shuttle-Type Screen Will Be "Stable"
  - Most Vapor Will Pass Through and Rise Through Feedline if Screen is not Flat, Horizontal
  - Feedline may be Saturated or not have Repeatable Performance
  - Analytical Models have not been Confirmed
  - Helium Bubbling, If Used, Will Not Result In Evaporative Cooling at Engine Inlet (Assumes Ambient Helium)
  - Possible Design Solutions
    On Board Bleed
    Overboard Bleed



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Several subsystem concepts were considered for feedline and pump conditioning. A specific recommendation will not be made at this time and in this phase of the design study because of the preliminary nature of the study, although some of the concepts have characteristics that are obviously more desirable than those of others. The attributes that were considered in evaluating the subsystem concepts are shown on the facing page.

The evaluation of candidate subsystems against these attributes is summarized later.

## Attributes Considered in Evaluating Systems

- Effect on LOX Tank Design Pressure
- Predictability
- Repeatability, Engine Test to Vehicle
- Precedence
- Impact on Engine Design
- Impact on Engine Test
- Potential for Required Future Change
- Operational Efficiency
- Hazard Introduced
- Hardware Complexity

## The On-Board Bleed

The first concept considered was the On-Board Bleed, which has no ground interface and does not vent to the atmosphere. A LOX flowrate of 0.85 lb/sec. in the return line was calculated for a 2 Btu/sec engine heat leak. This would allow the "hot" LOX to be carried up the return line and the LOX flowing down the feedline would be heated to 171 deg R at the pump inlet and 180 deg R in the pump. This would provide a net positive pressure of 72 psi at the pump inlet and 50 psi in the pump for engine start. This concept would eliminate prepressurization as a LOX tank design factor, because the maximum tank bottom pressure in flight is only 14 psig lower than during prelaunch with a 50 psig prepressurization ullage pressure. The bleed was assumed to originate in the gas generator supply line downstream of the LOX pump.

The predictability of the On-Board Bleed was considered "fair" because it has not been used recently, and it does not have a mechanical pump. The analysis is straightforward. The repeatability, engine test to vehicle was considered good, because the configuration would not be hard to duplicate. The Saturn IB precedent was virtually identical to this application.

The impact on engine design and test is expected to be moderate. An engine bleed valve would be required.

The potential that a future change would be required is considered low, however the available bleed flow rate is limited by the head available for natural convection. Therefore, the only way to increase the flow rate is to enlarge the bleed line. Also, if the vehicle boattail is shortened to allow a longer hydrogen tank, the bleed line head would be reduced, reducing the bleed line flow rate.

We consider the operational efficiency of this concept to be good because it has no ground interface, although it does add a bleed valve to each engine and this bleed valve might fail.

The hazard introduced would only be that one of the small lines might fail and create a LOX leak. The hardware required for this scheme is not complex, only a bleed valve and set of small lines and brackets for each engine is required.

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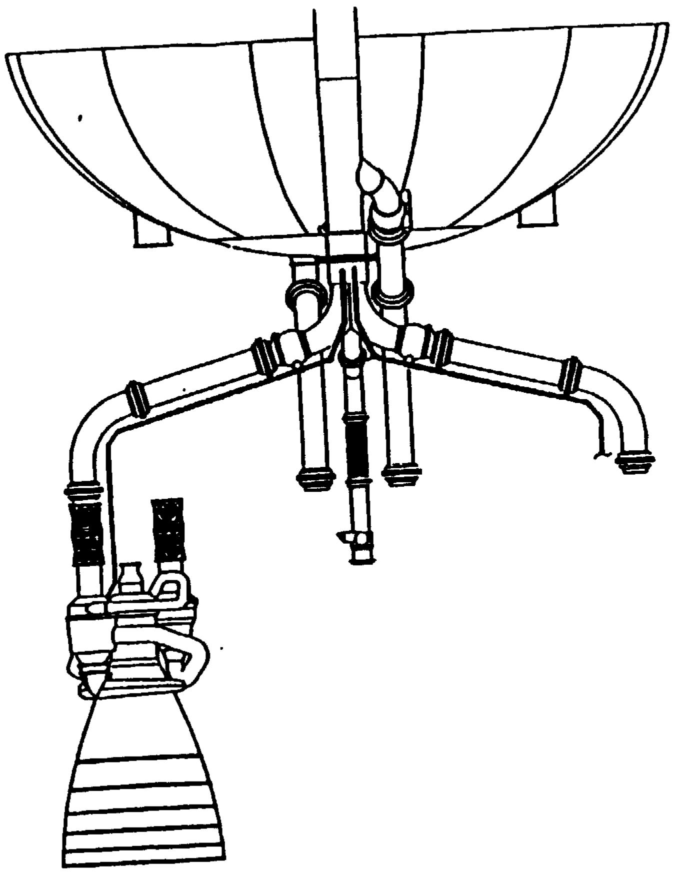

## Onboard LOX Bleed

- Onboard Bleed Flows 0.9 lb/sec
- Eliminates Stagnation in Feedline and STME
- Provides Subcooled LOX at STME Inlet and in LOX Pump
  - 171°R at Inlet — 72 psi above Vapor Pressure
  - 180°R in pump — 59 psi above Vapor Pressure
- Provides Repeatable Engine Operation Conditions from test Stand to Vehicle
- Simple Design (Similar to S-1 Stage)
  - Bleed Valve (Similar to SSME) Near GG Inlet
  - One Inch ID LIne with 12 ft. Head
- No Ground Interfaces
- No Separation Interfaces



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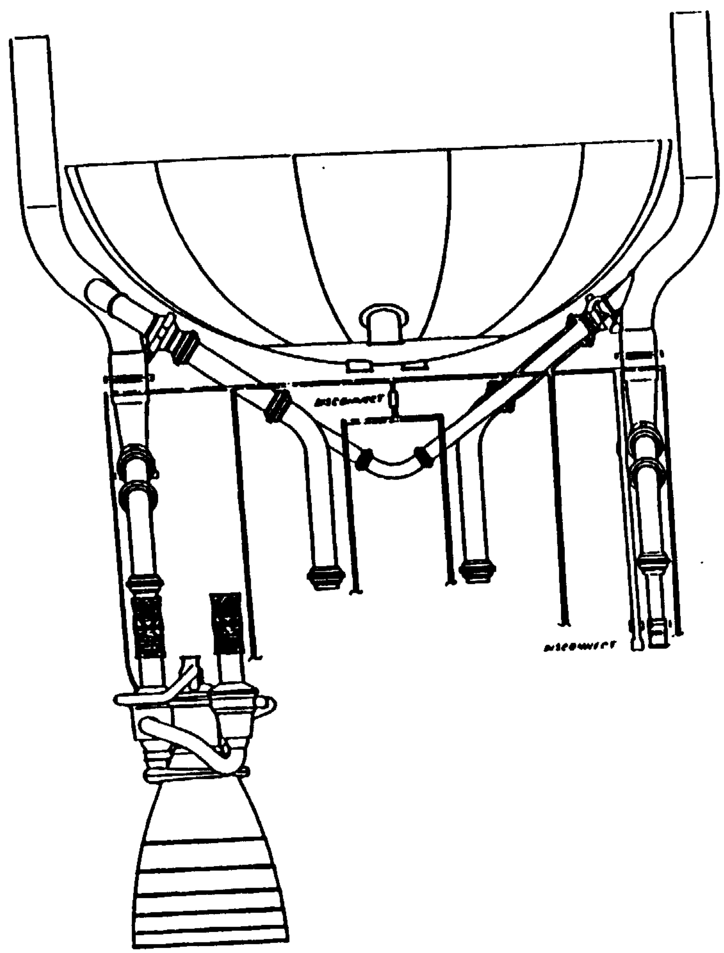
## The Overboard Bleed to the Facility

The overboard bleed to the facility is quite similar to the on-board bleed in its performance except that the total head of the LOX above the engines can be used to drive the flow, rather than only the convective loop created by the feedline and the warmer return line. The flow was calculated for a system comprising 1/2 inch lines manifolded to a 1-1/2 inch line which carries the flow to a ground disconnect, thus overboard to the facility. This is very similar to the Shuttle LOX bleed and is predictable, repeatable, easy to duplicate on a single engine test stand, and robust from the standpoint that even with small lines a high flow rate (2.2 lb/sec) can be obtained. The predicted engine inlet temperatures are actually three degrees F lower than with the on-board bleed, even with the 1/2 inch lines which are half the diameter of the lines considered for the on-board bleed. For these reasons, the potential for a required future change was considered low. The operational efficiency was considered only fair because of the necessity of the ground interface and separate system to dispose of the oxygen bled to the ground. The hazard introduced was the same as the on-board bleed with the addition of the potential failure of the ground disconnect and potential leakage or failure of the on-board disconnect which is provided for booster separation. The hardware is more complex than the on-board bleed because of the in-flight disconnect, and because of the ground disconnect. Also, the 1-1/2 inch collector line and the ground disconnect add to the complexity.



## Overboard LOX Bleed

- Eliminates Stagnation In Feedline and STME
- Provides Subcooled LOX At STME Inlet and In LOX Pump
  - 168°R at Inlet
  - 171°R In Pump
- Provides Repeatable Engine Operating Conditions From Test Stand To Vehicle
- Bleed Valve Required Similar To SSME
- 1/2 Inch Diameter Line Manifolded to 1 1/2" Disconnect
- Adds Ground Interface (1 1/2 Inch Separation Disconnect)
- Adds Two 1/2 Inch Inflight Disconnects



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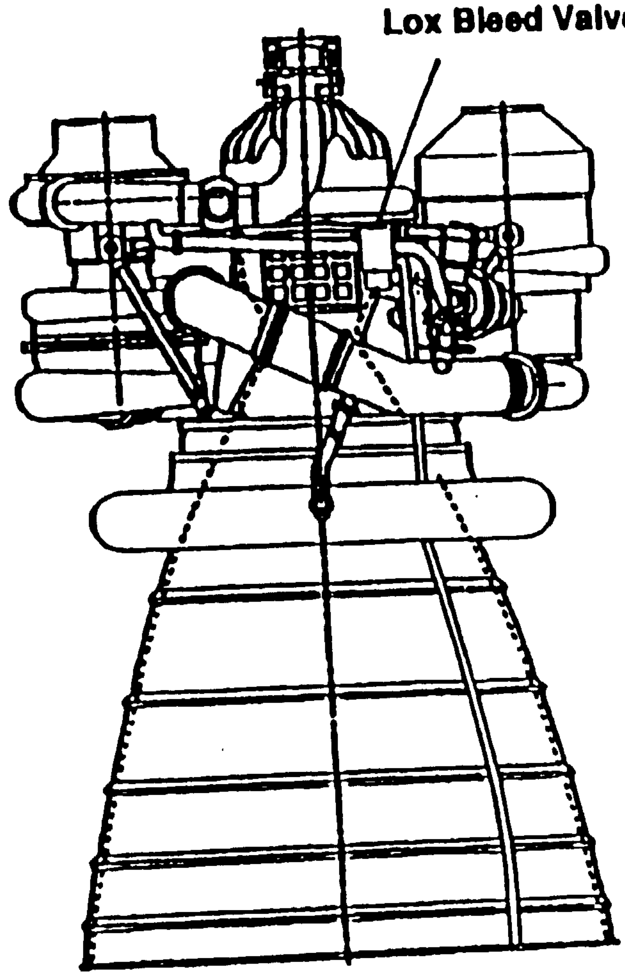
## The Overboard Bleed to the Atmosphere

The overboard bleed to the atmosphere, is suggested by the performance of the on-board bleed and the fact that the SSME discharges 0.5 to 2 lb/sec through its LOX bleed line to the atmosphere during prelaunch. This indicates that a flowrate equal to that of the on-board bleed (0.85 lb/sec) could safely be discharged to the atmosphere at the engine exit plane which is the location at which the SSME LOX pump seal bleed is discharged. If the gas generator LOX supply line is not the critical location for engine chill, it is possible that the engine labyrinth seal leak (if a labyrinth seal is used) would be all the bleed that is necessary. The performance would be identical to the on-board bleed to the level of detail the analysis has been done, and an engine thermal model would be necessary to tell the difference. This would give an engine inlet steady state LOX temperature of 171 deg R. Like the other bleed concepts, this would remove the high prepressurization requirement that would be required if the feedline is saturated. The concept is predictable since the flow is steady. The repeatability, engine test to vehicle, would be excellent if the feedlines had similar heat leaks. If they did not, a means would have to be found to establish the same kind of a temperature gradient in the feedline, as expected for the flight vehicle. This method, except for the Shuttle experience cited above, has no known precedent. Again this method would require an engine bleed valve. There would be virtually no impact on engine test. This concept appears to be robust, and the possibility of requiring a future change appears to be low. The operational efficiency appears to be good. The hazard introduced by this concept is considered to be minimal. Hardware complexity is not a problem, since the concept requires only a bleed valve and a small drain line. If the engine pump seal leak can satisfy the need for the bleed, only the drain line would be needed.

## Overboard Bleed to Atmosphere

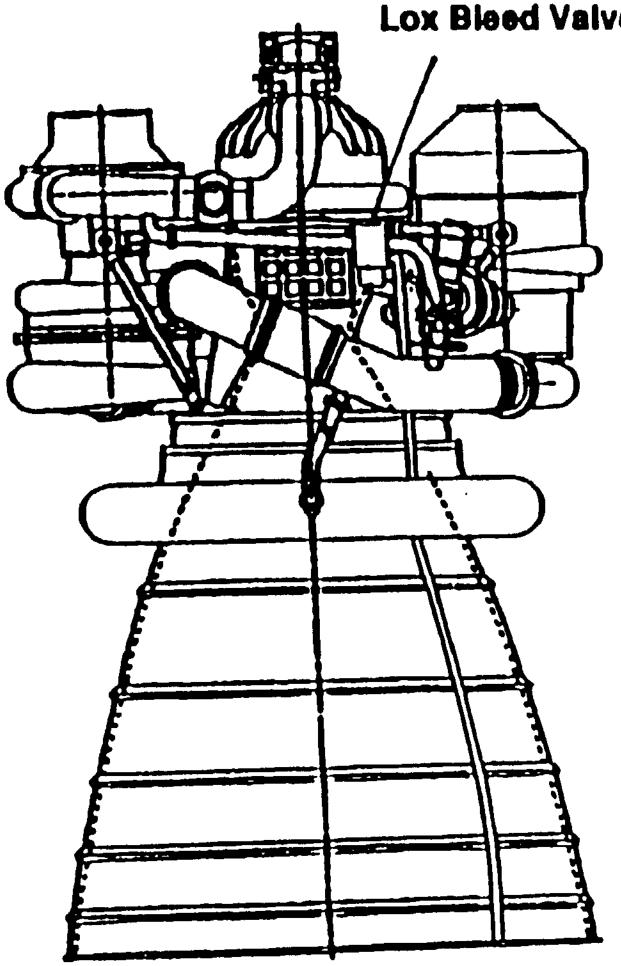
- LOX Bleed Overboard to Atmosphere at Engine:
  - -Performance same as Onboard LOX Bleed for 0.9 lb/sec Bleed from GG LOX Supply Line
  - -SSME LOX Pump Intermediate Seal Currently Leaks 0.5 to 2 lb/sec of LOX with no known Ill Effects
  - -Bleed Valve (similar to SSME) Required
  - -May require adding Bleed Line to Engine Exit
  - -No Interfaces, no Disconnects



## Start With LOX Lead

Starting with a LOX lead did not appear to be a favorable concept. It does not appear realistic to dump several hundred pounds of LOX during start and follow it with partially burned combustion products and it does not appear favorable to require the engine to traverse the range of mixture ratios from LOX rich to its normal operating point during start. It has been suggested that a LOX lead could be followed by a purge, and then the engine started normally, and this might be satisfactory, but it would impose an additional development requirement on the engine. Neither method looks to be predictable. The RL-10 precedent does not look applicable because the RL-10 cycle is completely different from the one selected for the STME. The engine test program would have to explore a range of inlet conditions to be expected in use, adding a number of tests to the development program. The method, because it does not look predictable, would have a tendency to have to be changed. The feedline temperature at engine start has not yet been predictable, and temperature interlocks may be required to assure a satisfactory start. There are so many unknowns about this method, that it appears to be impossible to evaluate the associated hazard. The advantage is that it does not add any components.

## Start with LOX Lead




- Engine Start with LOX Lead:
  - Places Constraint on Engine Sequence Not Connected with Starting the Engine Itself
  - Forces Engine to Traverse Mixture Ratio Range from LOX Rich to Fuel Rich
  - Potential Increase in Engine Testing Required as Compared to Bleed

## Summary

The upper flow loop is considered to be a viable anti-geyser and propellant conditioning approach.

The reference No-Bleed system is not predictable, so far, and may result in saturated LOX in the engine inlet and in the engine. Any attempt to make such a prediction is complicated by the assumed requirement for a screen in the feedline. To predict the No-Bleed system performance, an analytical model and test data to verify it are needed. Since this is the case, the tank must be designed to accommodate a high prepressurization requirement, which is expected to cause a higher tank bottom pressure than encountered in flight. Also, because of this unpredictability, it appears that the engine test program would be complicated by the need to evaluate a wide range of inlet conditions and hold time. Also, thermal constraints that might require real time evaluation may come out of such an engine test program.

Of the bleed systems, the bleed to the atmosphere is the simplest, and the pump seal leakage may provide all or most of the necessary flowrate. The On-Board Bleed is viable, with an addition of complexity. The Overboard Bleed to the facility is low-risk, and may even be considered standard, since it is used on the Shuttle, but it does add operational and hardware complexity.

The idea was brought up to start with a LOX lead to expel any hot LOX. Since this would impose an additional development requirement on the engine and seemed questionable from a safety and engine operability standpoint, it is not recommended.

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## Evaluation Matrices

The two evaluation matrices on the following pages summarize the above discussion of the candidate subsystems.

## LOX FEEDLINE CONDITIONING

| Attributes | Reference No Bleed | On-Board Bleed | Overboard Bleed To Facility | Overboard Bleed to Atmosphere | Start after LOX dump thru MOX |
|---|---|---|---|---|---|
| •Effect on LOX Tank Design Pressure | •Prepress to 50 psi Increases Tank Design Press. 3700 lb weight Impact | •Deletes Prepress Reqt. Penalty | •Deletes Prepress Reqt. Penalty | •Deletes Prepress Reqt. Penalty | •Prepress to 50 psig. Increases Ullage & Tank Bottom Design Pressure |
| •Predictability | •Poor | •Fair | •Excellent | •Good | •Excellent |
| •Repeatability Eng. Test to Vehicle | •Poor | •Poor | •Very Good | •Good | •Very Good |
| •Precedence | •None | •Saturn 1B S-1 Stage | •Shuttle | •Shuttle Shows Safety, Not Performance | •None |
| •Impact on Engine Design | •None | •Adds LOX BV | •Adds LOX BV | •Adds LOX BV and small line | •Causes MR Traverse from High to Normal |
| •Impact on Eng Test | •None | •Low | •Very Little | •Low | •Potentially Large |
| •Potential for Req'd Future Change | •Large | •Low (Limited Bleed Rate) | •Very Low (High Bleed Rate) | •Low (Limited Bleed Rate) | •Large |
| •Operational Efficiency | •Good | •Good (Pending Test) | •Fair | •Good (Pending Test) | •Unknown |
| •Hazard Introduced | •None | •Low | •Low | •Low | •Potentially Severe |
| •Hardware Complexity | •Low | •LOX BV's & Small Lines Req'd | •LOX BV's Small Lines & Onbd & Grd Disconnects Req'd | •LOX BV's and Drainlines Req'd | •Low |



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# LOX FEEDLINE CONDITIONING EVALUATION MATRIX

3 - Important
2 - Somewhat Important
1 - Considered

Grades = A=4, B=3, C=2, D=1 F=0
Score = Grade · Weight

Grades/Scores

| Attributes | Weighting Factor | Reference No Bleed | On Board Bleed | Overboard Bleed to Facility | Overboard Bleed to Atmosphere | Start after LOX dump thru MOV |
|---|---|---|---|---|---|---|
| Effect on LOX Tank Des. Press. | 3 | 0 / 0 | 3 / 9 | 4 / 12 | 4 / 12 | 0 / 0 |
| Predictability | 2 | 0 / 0 | 2 / 4 | 4 / 8 | 2 / 4 | 4 / 8 |
| Repeatability Eng. Test to Vehicle | 3 | 0 / 0 | 0 / 0 | 3 / 9 | 2 / 6 | 3 / 9 |
| Precedence | 2 | 0 / 0 | 2 / 4 | 4 / 8 | 2 / 4 | 0 / 0 |
| Impact on Eng. Design | 1 | 4 / 4 | 2 / 2 | 3 / 3 | 2 / 2 | 4 / 4 |
| Impact on Eng. Test | 1 | 4 / 4 | 2 / 2 | 3 / 3 | 2 / 2 | 1 / 1 |
| Potential for Req'd Future Change | 2 | 0 / 0 | 1 / 2 | 4 / 8 | 2 / 4 | 0 / 0 |
| Operational Efficiency | 3 | 4 / 12 | 3 / 9 | 1 / 3 | 3 / 9 | 2 / 6 |
| Hazard Introduced | 3 | 4 / 12 | 3 / 9 | 2 / 6 | 3 / 9 | 0 / 0 |
| Hardware Complexity | 1 | 4 / 4 | 3 / 3 | 2 / 2 | 3 / 3 | 4 / 4 |
| Total | | 36 | 44 | 62 | 55 | 32 |



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## Cost Estimates

The hardware cost estimates on the facing page are for the bleed systems described. The option alpha-numerics are those assigned by NASA.

## LO2 Options

| Option A-1 - On-Board LO2 Bleed | | | | |
|---|---|---|---|---|
| **Item** | **Description** | **Qty/PM** | **Cost/Unit** | **Cost/PM** |
| Engine Bleed Valve | Similar to SSME (1 Per Engine) | 6 | 81,613 | 489,678 |
| Line | 1.125" ID X 9.5' Line W/3' Flex | 6 | 110 | 713 |
| Elbow | 1.125" ID 75°, R/d >= 2.5 | 6 | 23 | 138 |
| Line | 1.125" ID X 10.5' Line W/3'Flex | 6 | 131 | 788 |
| Elbow | 1.125" ID 75°, R/d >= 2.5 | 6 | 23 | 138 |
| Line | 1.125" ID X 2.5' Line W/3' Flex | 6 | 31 | 188 |
| Elbow | 1.125" ID 75°, R/d >= 2.5 | 6 | 23 | 138 |
| Inlet Fitting | Connection to Lower F/L Discon | 6 | 150 | 900 |
| **Total** | | | | **492,681** |



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## Option C-1 - Overboard LO2 Bleed

| Item | Description | Qty/PM | Cost/Unit | Cost/PM |
|---|---|---|---|---|
| Engine Bleed Valve | Similar to SSME (1 Per Engine) | 6 | 81,613 | 489,678 |
| Line | 0.5" ID X 9.5' Line W/3' Flex | 6 | 119 | 713 |
| Tee | 0.5" ID | 6 | 50 | 300 |
| Disconnect | 0.5" ID | 1 | 26,000 | 26,000 |
| Elbow | 0.5" ID 90°, R/d >= 2.5 | 6 | 2 | 13 |
| Line | 0.5" ID X 1' | 6 | 2 | 13 |
| Elbow | 0.5" ID 30°, R/d >= 2.5 | 6 | 1 | 4 |
| Line | 0.5" ID X 12' | 6 | 26 | 155 |
| Manifold | 0.5" To 1.5" ID | 1 | 10,000 | 10,000 |
| Line | 1.5" ID X 12' | 1 | 234 | 234 |
| Elbow | 1.5" ID R/d >=2.5 | 1 | 57 | 57 |
| Line | 1.5" ID X 2' | 1 | 39 | 39 |
| Disconnect | 1.5" ID | 1 | 26,000 | 26,000 |
| **Total** | | | | **553,206** |

| Option D - Overboard Bleed To Atmosphere<br>(This is engine mounted hardware) | | | | |
|---|---|---|---|---|
| Engine Bleed Valve Line | Similar to SSME (1 Per Engine)<br>0.5" ID X 12.5' (Insulated) | 6<br>6 | 81,613<br>27 | 489,678<br>161 |
| **Total** | | | | **489,839** |

# Task 3-P-019
## Addendum

| Weight Estimates | lb. |
|---|---|
| • On-Board LOX Bleed (Option A-1) | 107 |
| • Overboard LOX Bleed (Option C-1) | 68 |
| • Overboard Bleed to Atmosphere (Option D (Engine Mounted Hardware)) | 56 |

## Summary & Conclusions

- Reference No Bleed System cannot be expected to have subcooled propellant at engine inlets at start of prepressurization.
- Reference No Bleed System causes tank prepressurization pressure increase. A 20 psi prepressurization increase to 50 psig results in a 3700 lb. tank weight impact.
- Warm up (vapor pressure increase) after prepressurization is very slow - approximately 0.4 psi/min.
- The Onboard Bleed looks viable and eliminates the penalty due to prepressurization requirements.
- The Overboard Bleed to the facility provides good performance but at the cost of increased complexity.
- The Overboard Bleed Through the Engine to the atmosphere provides good conditions and is simple, only a bleed valve and a line to the nozzle exit are required.
- The LOX dump appears to unduly burden the engine development program unless the engine is designed for LOX lead start.

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# Task Number 3-P-025

# LO2 Tank Pressure Limits

Prepared By:
Tom Winstead
20 Dec, 1991

Approved By:
Z. Kirkland

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# Executive Summary

NASA Statement of Work:

"Establish LO2 tank pressure limits vs. flight time considering engine start, shutdown and NPSP requirements, potential pressure stabilization of tank during max airloads, structural weight considering proof test requirements and performance."

- With no-bleed LO2 system, prepressurization will determine tank structural requirements. Current estimate of tank impact ~4500 lbm. For no impact on tank, prepress needs to be reduced to <30 psig.
- Vent valve for baseline will be sized by prelaunch operations and will have no influence on flight.
- Optimum NPSP at MECO is 30.8 psi at an ullage pressure of 20.0 psig.
- Proposed system would have a prepressurization band of 30-32 psig with relief set at 34 psig. Structural impact of ~500 lbm is largely offset by a reduction in residuals

# Task Number 3-P-025
# LO2 Tank Pressure Limits

## 1.0 Summary

The study has shown that the upper pressure limit will be determined by prelaunch operations. This results in a 4500 lbm increase in structural weight. This impact can be eliminated by using a bleed conditioning system and reducing the pre-pressurization level to less than 30 psig. Lower limit is determined by the saturation pressure of the liquid up to terminal drain when the engine NPSP requirement of 30.8 psi becomes important. The optimum tank pressure is ~20 psig which allows the autogenous pressurization flowrate to be reduced from the reference 3.0 lbm/sec to 2.5 lbm/sec.

## 2.0 Problem

Determine LO2 tank pressure limits for the reference configuration.

## 3.0 Objective

Determine tank and system impacts for the reference configuration.

## 4.0 Approach

The approach to performing this study was:

- Determine tank pressure vs. time for baseline trajectories.
- Use inputs from 3-P-018, 3-P-019, 3-P-017 and 3-S-010A to determine system impacts.

## 5.0 Results

The results of this study are attached. The primary results of the study are listed below.

## 6.0 Conclusions and Recommendations

The upper limit will be sized for pre-launch operations.

Current autogenous flowrate can be reduced to lower tank pressure at MECO.

Insulated LOX tank.

Helium Inject.

Recommend 30-32 prepress band with minimum relief at 34 psig.

## 7.0 Supporting Data

## 8.0 Attachments

Study "Task Number 3-P-025, LO2 Tank Pressure Limits," dated 12/20/91.

# Task Number 3-P-025

# LO2 Tank Pressure Limits

# Attachment-Detailed Data

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## Approach

Generate baseline ullage pressure for HLLV and 1.5 Stage

Generate issues with system and structural impact

Trade residuals with engine NPSP requirements and engine cost sensitivities

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The STME cost and weight impacts associated with NPSP variations are from the STPT consortium. The data are contained in NLS Data Book Log #35 in response to an action item from the propulsion TIM #1.

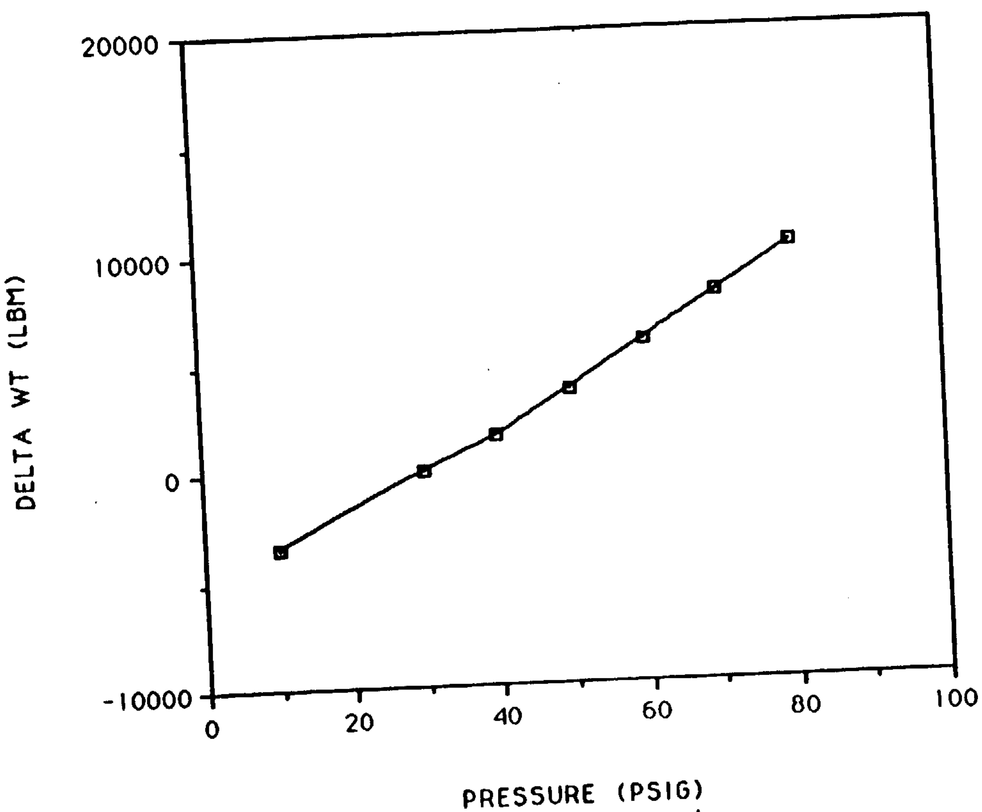
## Assumptions

- Analysis based on reference layout
- Engine out trajectory used for MECO conditions
- STME influences taken from NMO-090-20
- LO2 tank structural impact derived from 3-S-010A Trade

The LOX Tank Trade Study 3-S-10A was done predominantly above 30 psig according to requirements for that study. The facing figure has been extended to 10 psig, where the stringer weights will start increasing. No analysis has been done below that pressure. The LOX tank skin will go into compression at about 25 psig, and some structural designers prefer to not operate the tank in compression.

The raw material cost differential is estimated at about $350/lb.

# LOX Tank Structural Weight



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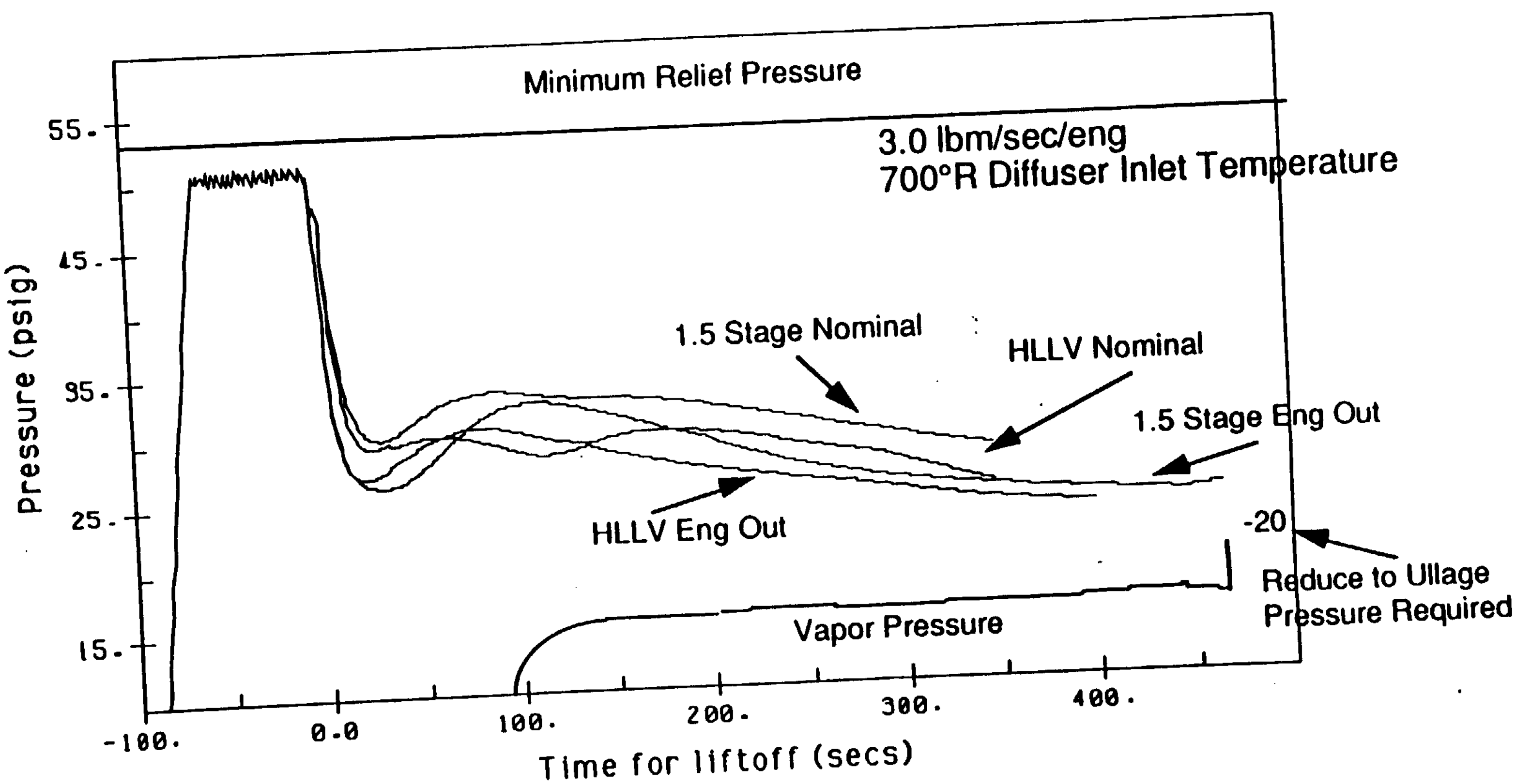
A typical LOX tank ullage pressure profile is shown for selected 1-1/2 stage and HLLV trajectories for the cycle-0 baseline pressurization system (700 deg R autogenous, fixed orifice flow control, and no engine bleed). Note that the pressure near booster separation is about 8 psig higher than at cutoff. While the NPSP requirement is approached only as the feedline is drained, the tank pressure at cutoff will generally have a minimal effect on structural design; the structure is more than likely designed by tank bottom pressure near booster cutoff when this pressure and other loads are converted to tank proof pressure requirements.

If the no-engine-bleed option was retained, prepressurization and liftoff loads would probably design the tank. The weight impacts are unacceptable and retention of this option is not recommended.

## Baseline Ullage Pressure



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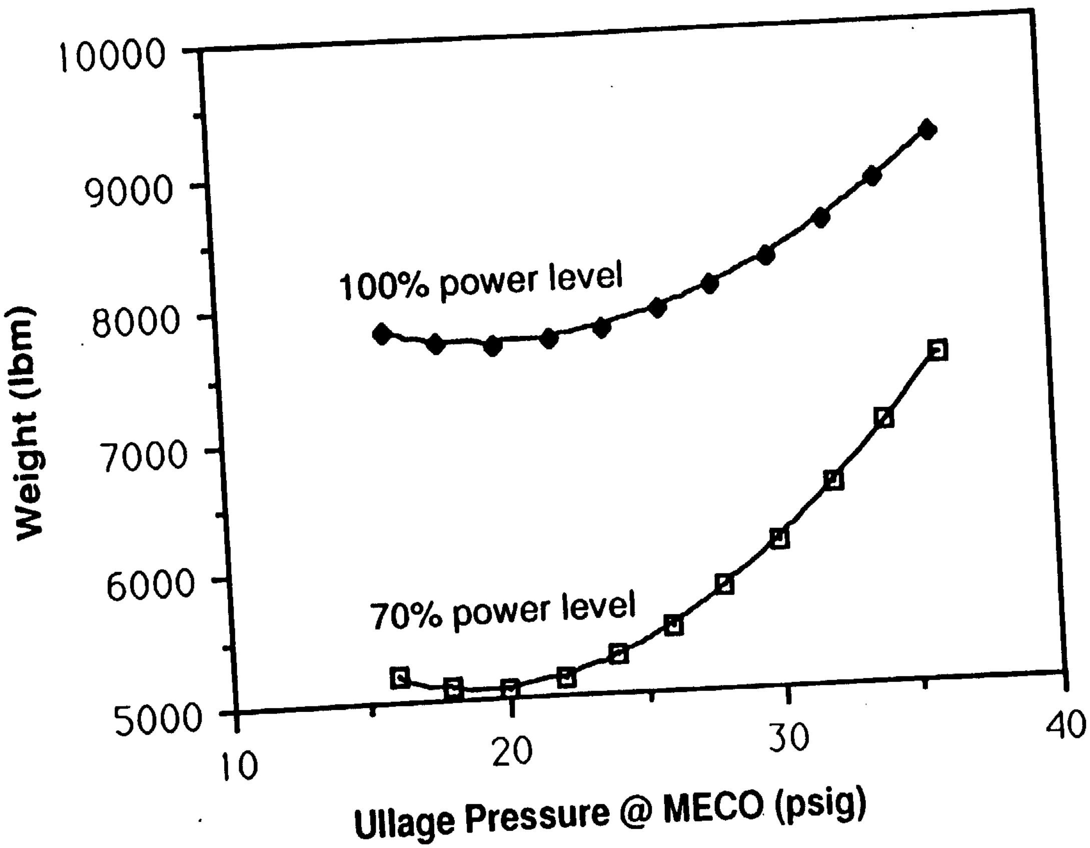
These curves show the payload sensitivity using the "baseline" NPSP of 30.8 psia, evaluating residuals for cutoff from 70 and 100% power levels.

The predominant factors differentiating these curves is the reduction in unusable propellant mass in the feedlines. The gain in payload is significant, and warrants a recommendation to plan to operate the engines at 70% for a predetermined period prior to cutoff.

While the feed system layout and performance values are preliminary, this trend will apply to all configurations, although absolute values will vary.

## Payload Sensitivity due to Power Level



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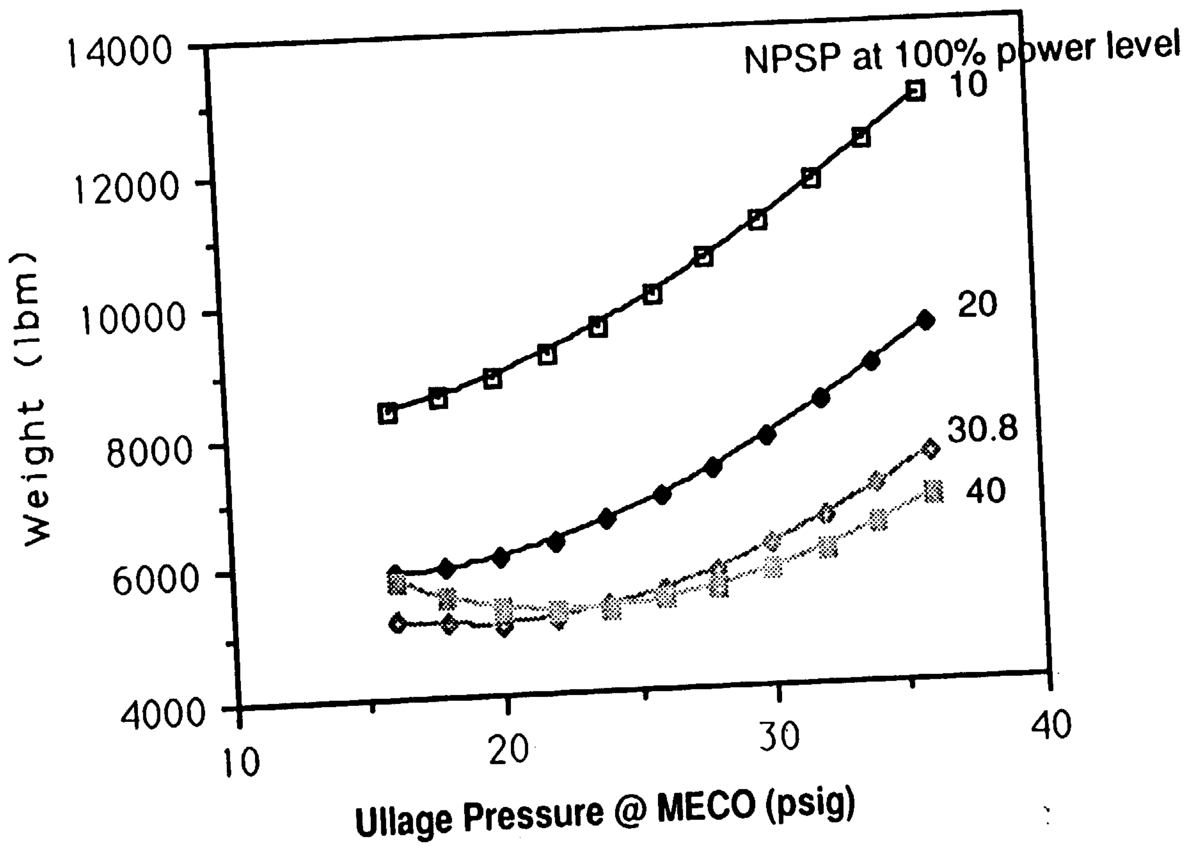
Extending the analysis to parametric NPSP requirements shows that the baseline NPSP is probably near a minimum, but that there is a small influence on the system payload capability over a fairly wide range of NPSP and tank pressures.

As tank pressure at MECO is increased, the structural weight increases, but residuals for an engine out are decreased so that the net payload impact is small.

Elements considered here are residuals at a vapor pressure of 20.2 psig, ullage weight at MECO, and structural weights corresponding to conditions near booster cutoff, pump weights corresponding to the NPSP and cutoff from 70% power level.

# Payload Impact at 70% Power Level



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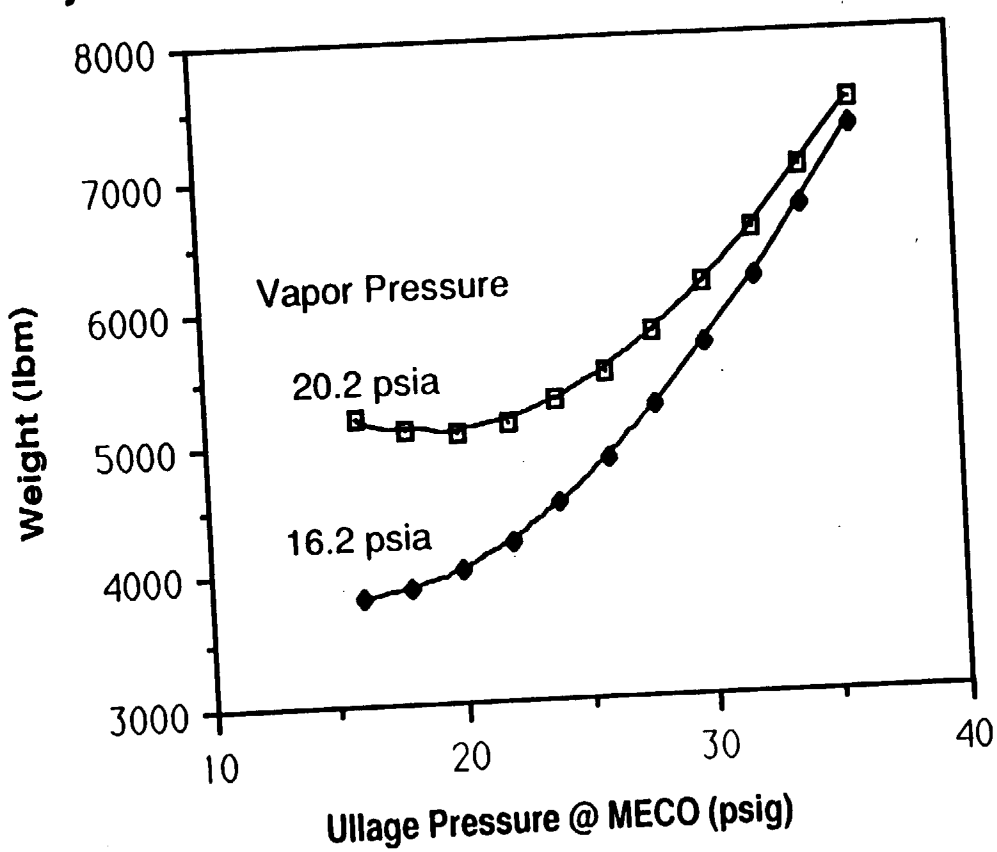
The liquid vapor pressure at MECO has been assumed to be a constant 20.2 psia for all of the above trades. As minimum tank pressures are approached, there is an increasing gain for reduced vapor pressure.

The 16.2 psia condition corresponds to Shuttle ET LOX vapor pressure, which results from a well insulated tank with a significant period of helium injection prior to launch which leaves the propellant in a well established recirculation mode throughout flight.

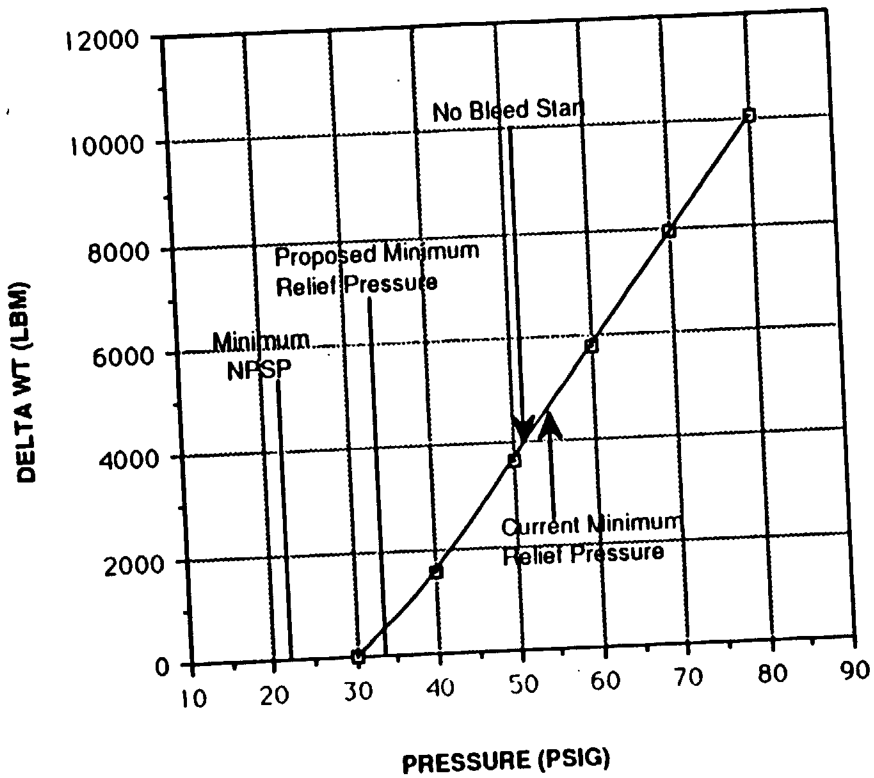
The 20.2 psia condition corresponds to an uninsulated LOX tank without helium injection with the tank pressurized above 22 psia.

## Payload Sensitivity due to Liquid Vapor Pressure



The tank pressures and weight impacts associated with the reference design and the resulting requirement for a high prepressurization level corresponding to the no bleed engine start. The proposed minimum relief pressure and minimum tank pressure reduce the tank weight penalty, (compared with a tank operating at Shuttle ET pressure, from 4500 to 500 lbs.).

LO2 Tank Structural Impact

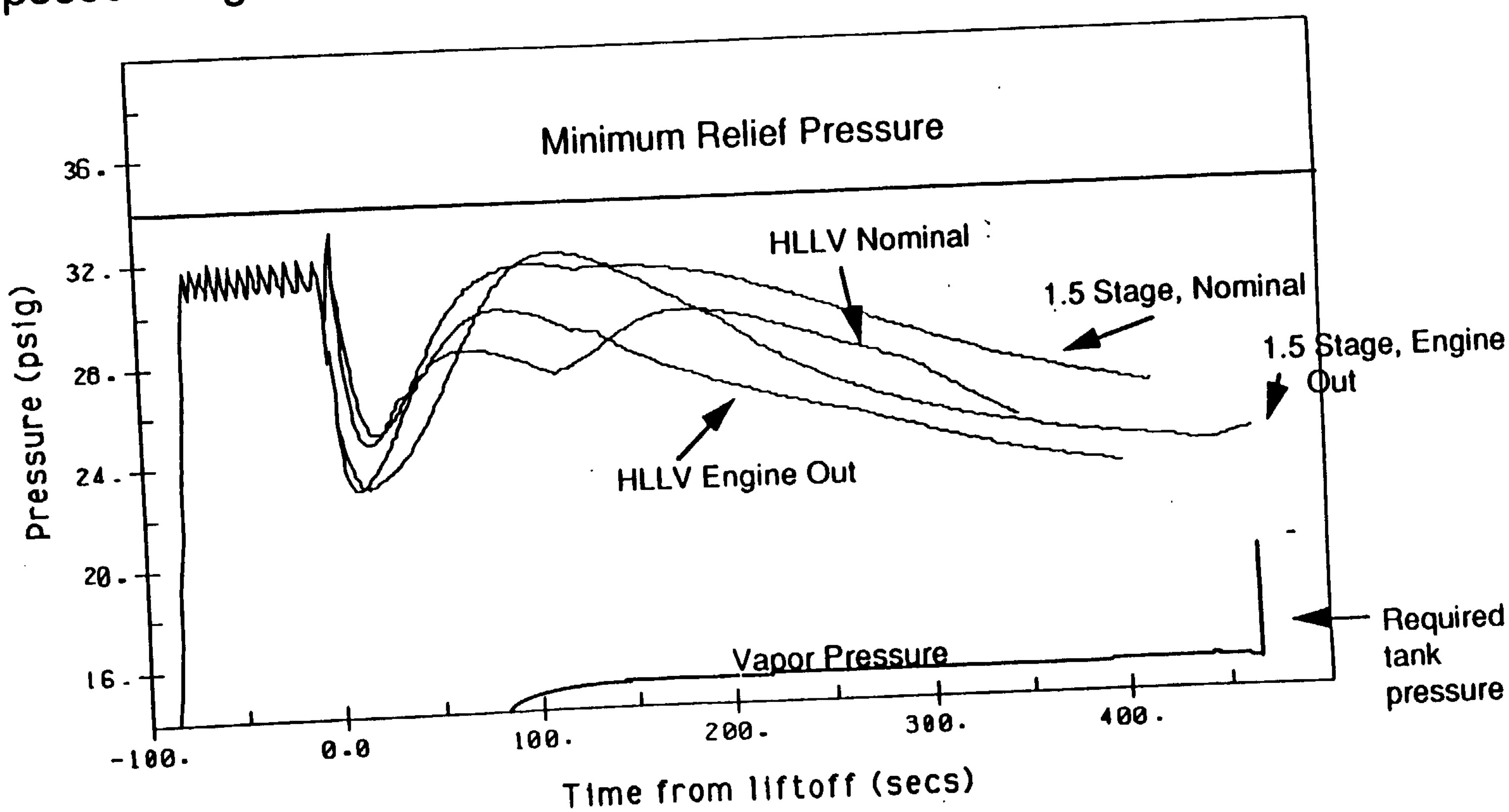


The proposed LOX tank pressure band of relief valve set at 34 psig is a companion to fixed orifice autogenous pressurization, engine conditioning of some type, and system optimizing near 20 psig @ MECO.

The nominal predictions on tank pressure are oversimplified by ground rules, and will experience some additional variations as components and STME operation are further defined.

If a flow control system were incorporated, the maximum tank pressure could be reduced, and would provide performance improvements.

# Proposed Ullage Pressure



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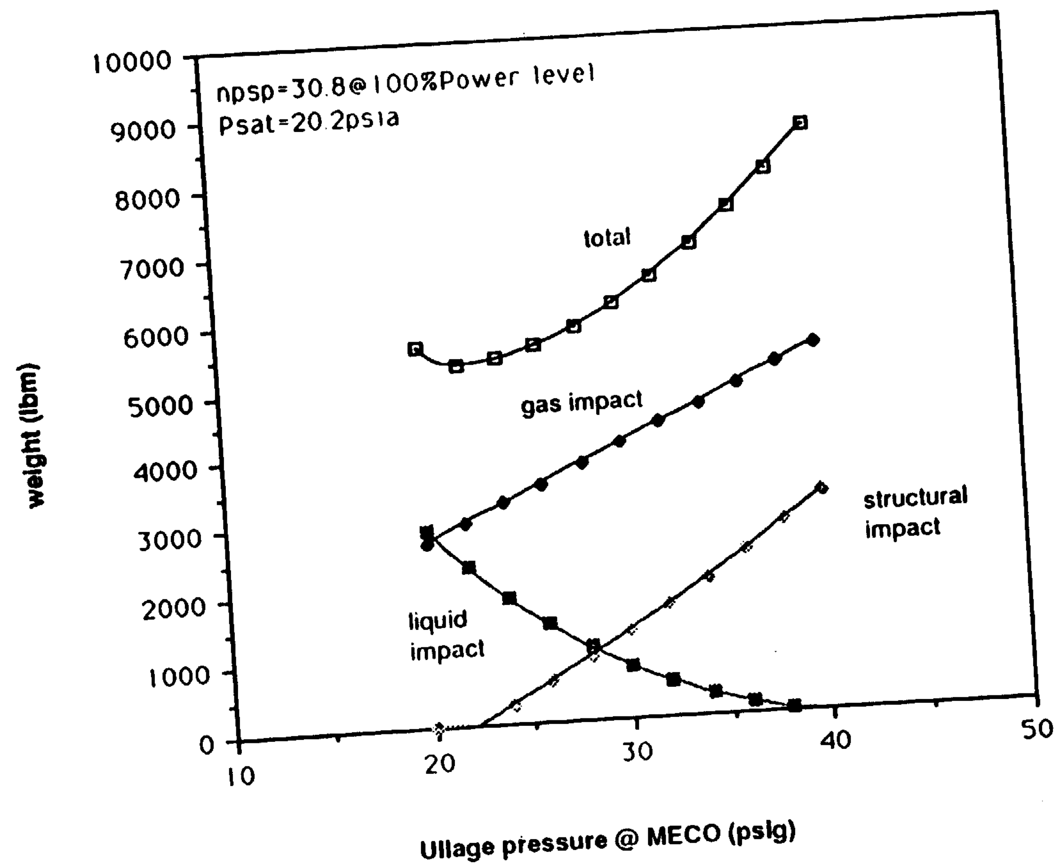
When system payload impacts are evaluated:

- The tank pressure effect on weight is evaluated at BECO ($\Delta P = 8$ psig higher than at MECO)
- Liquid residuals are evaluated at the time when NPSP is no longer satisfied
- Gas residuals are those required for tank pressurization

Elements which would further increase payload are:

- Vapor pressure less than 20.2 (page 7)
- Tank pressurant flow-control ($\Delta P < 8$ psig)

## Payload Impacts at Proposed Tank Pressure



## Summary & Conclusions

- With no-bleed LO2 system, prepressurization will determine tank structural requirements. Current estimate of tank impact ~4500 lbm.
- Vent valve for baseline will be sized by prelaunch operations and will have no influence on flight
- Optimum NPSP at MECO is 30.8 psi at an ullage pressure of 20.0 psig
- Proposed system would have a prepressurization band of 30-32 psig with relief set at 34 psig. The structural impact of ~500 lbm will be offset by lower residuals at MECO.
- An intelligent tank pressure control system would result in a payload increase, but requires structural analysis.
- Residuals are significantly lower for an insulated/helium injected tank than for an uninsulated tank.

# Task Number 3-P-026

# LOX Tank Pressurization System Using Helium

Prepared By:
T. Winstead
20 Dec, 1991

Approved By:
Z. Kirkland

MARTIN MARIETTA
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## Executive Summary

**NASA Statement of Work:**

"Select optimum LO2 tank helium pressurization system based on tank pressure limits and specified reference trajectories and considering safety, reliability, operability, simplicity, weight, including residuals and cost."

**1.5 Stage**

- Minimum pressurization system weight is achieved using cryogenic storage helium.
- Ambient storage helium is the next best with fixed orifice autogenous being better at higher HEX temperatures.

**HLLV**

- Minimum pressurization system weight is achieved using cryogenic storage helium.
- Fixed orifice autogenous weight performance is better at higher HEX temperatures.
- Ambient helium system assumes no bottle staging and consequently will result in significant weight impact.

**Task Number 3-P-026**
**LOX Tank Pressurization System Using Helium**

## 1.0 Summary

A trade study was performed to evaluate LOX tank pressurization with ambient and cryogenic helium systems. A rough order of magnitude study for the autogenous pressurization system was done for comparison. Both ambient and cryogenic helium pressurization systems are lighter than an autogenous system, with the difference reducing as heat-exchanger outlet temperature is increased. The subsystem costs are significantly higher for the helium pressurization system.

## 2.0 Problem

A design concern for autogenous pressurization is that particulate ignition in the heat-exchanger discharge (pressurization supply) lines offers a catastrophic vehicle failure mode. The potential for failure increases in proportion to the selected heat exchanger discharge temperature.

## 3.0 Objective

The NASA statement of work is to "Select optimum LO2 tank helium pressurization system based on tank pressure limits and specified reference trajectories and considering safety, reliability, operability, simplicity, weight, including residuals and cost."

## 4.0 Approach

The approach was to perform an analysis of the baseline (autogenous) system varying heat exchanger outlet temperature to obtain the residual weight sensitivity. A similar analysis was performed for helium pressurization system, and design features were selected for systems at ambient and cryogenic storage. Cost and weight estimates were performed for all three systems and comparisons made.

## 5.0 Results

The system weight impact was compared by summing component and ullage weight. The payload weight impact is identical to the weight carried to orbit insertion, and increases as pressurant residuals are reduced. The autogenous system impacts payload by 4250 lbs. at the baseline conditions. The cryogenic helium storage system has a payload impact of only 3180 lbs., but at a cost increase of $1.2M/flight when compared to autogenous pressurization. An ambient helium system impacts payload by 5500 lbs., but this value can be reduced to about 4100 lbs. by staging bottles with booster engines. This system costs about $1.8M/flight more than autogenous.

## 6.0 Conclusions and Recommendations

Minimum weight is achieved using cryogenic stored helium. Ambient stored helium is the next lightest, with fixed orifice autogenous being better at higher HEX temperatures. There are more components and higher costs for the helium systems. The high-temperature GOX issue is traded with equally catastrophic bottle-failure issues.

## 7.0 Supporting Data

Task Number 3-P-017, "STME LO2 NPSP Requirements" and Task Number 3-P-025 "LO2 Tank Pressure Limits." Nein, M. E. and J. F. Thompson, "Experimental and Analytical Studies of Cryogenic Propellant Tank Pressurant Requirements, " NASA TN D3177, February 1966.

## 8.0 Attachments

Task Number 3-P-026, "LOX Tank Pressurization System Using Helium."

# Task Number 3-P-026

# LOX Tank Pressurization System Using Helium

# Attachment-Detailed Results

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## Approach

Perform baseline pressurization system analysis and vary heat exchanger outlet temperature to obtain residual weight sensitivity.

Generate pro/con's of system.

Perform helium pressurization system analysis to obtain similar pressure profiles.

Generate residual weight sensitivity.

Generate cost trade between baseline and helium alternatives.

## Baseline Fixed Orifice Pressurization System

- **Pro's**
  - Simple pressurization system
  - System weight reduced significantly with increase in HEX temperature

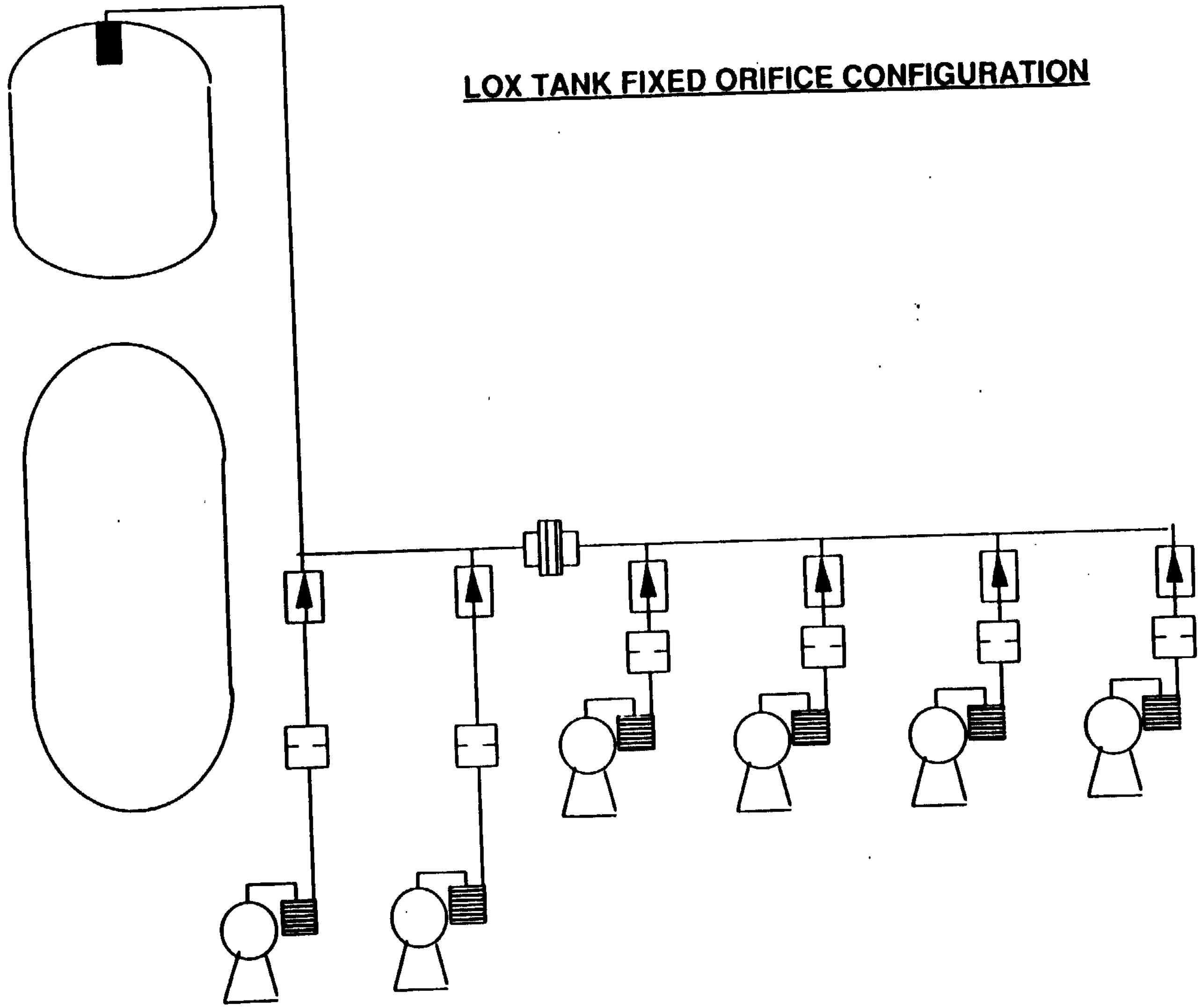
- **Con's**
  - Requires engine heat exchanger
  - Potential combustion with particle impact

The components for the autogenous fixed-orifice configuration consist of a heat exchanger, orifices, and check valves for each engine to accommodate engine-out. The orifice at each engine provides tank pressurant flow corresponding to the propellant use for that engine. The check valve isolates an engine which is not firing. For the 1-1/2 stage, the booster engines are manifolded with a single in-flight disconnect.

Tank prepressurization subsystems are identical, whether autogenous or helium pressurization systems are used, and are not shown as trade study discriminators.

The STME cost and weight impacts associated with NPSP variations are from the STPT consortium. The data are contained in NLS Data Book Log #35 in response to an action item from the propulsion TIM #1.

# LOX TANK FIXED ORIFICE CONFIGURATION

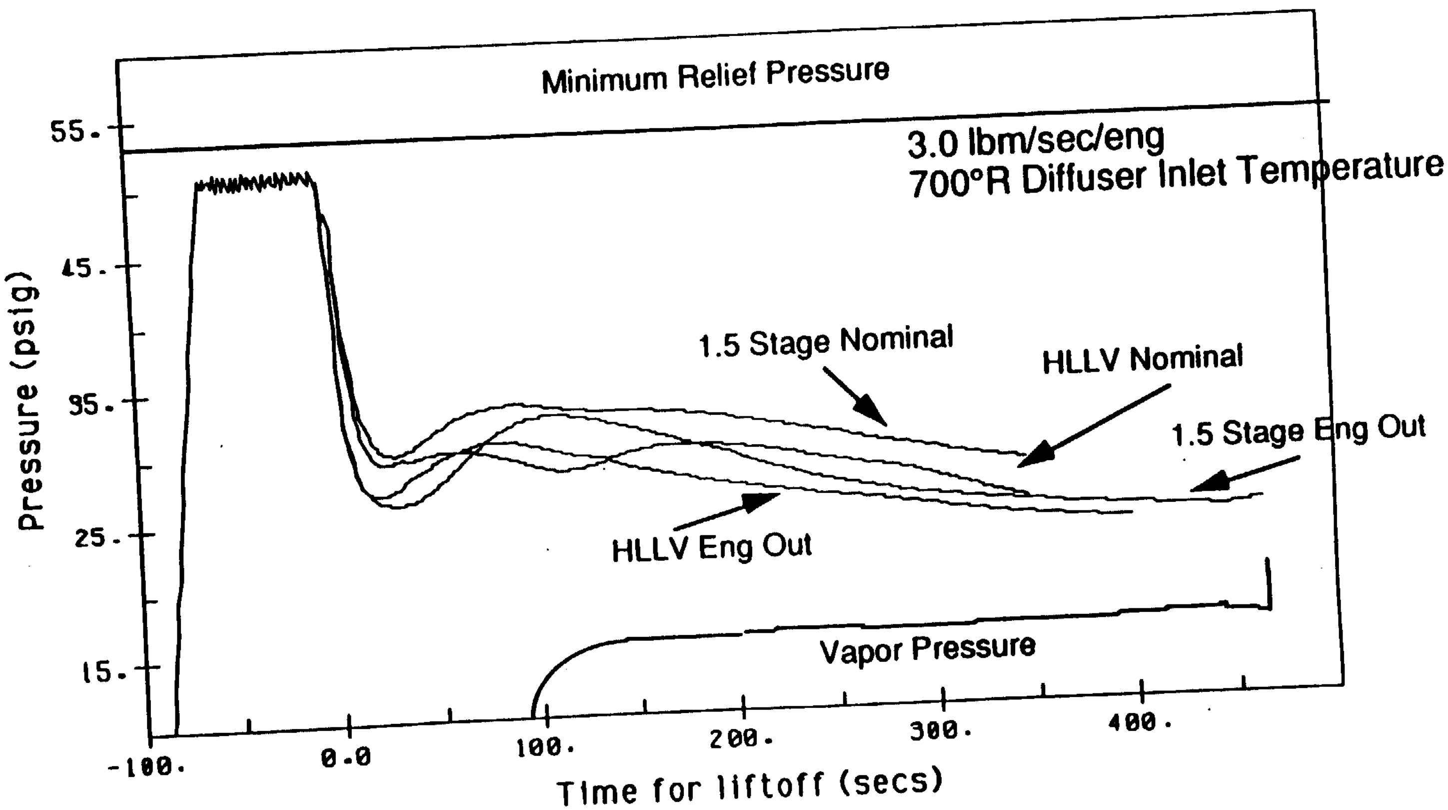


This analysis of autogenous fixed orifice performance was done to establish a reference for the helium system(s) studies presented later.

Cycle-0 baseline parameters are shown for a nominal HLLV and 1-1/2 stage including engine-out (at liftoff) system response.

The tank prepressurization does not correspond to the cycle-0 baseline; the No Bleed cycle-0 baseline resulted in severe system impacts as discussed in the appropriate trade study reports.

# Cycle Zero Baseline Ullage Pressure Profiles



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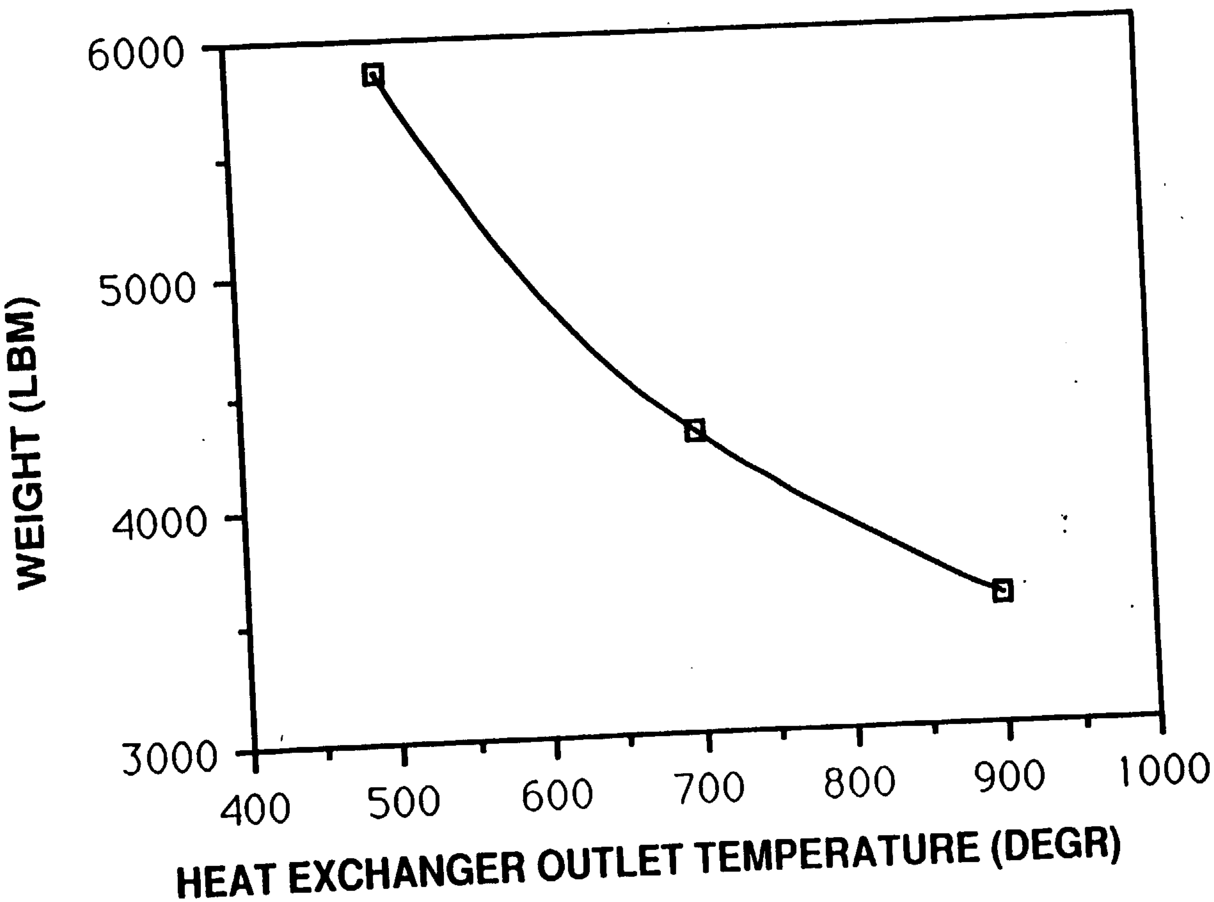
The pressurization system weight is the sum of hardware and ullage residuals at MECO. A decrease in this weight for an otherwise fixed launch system allows a corresponding increase in payload capability.

The hardware weight was assumed to be approximately that for the Shuttle ET, or about 450 lbs., and not a variable with heat exchanger outlet temperature.

The hardware cost was estimated to be $254K/flight.

## Autogenous Pressurization System Weight



## Cryo Helium Pressurization System

- **Pro's**
  - Low pressurization system weight

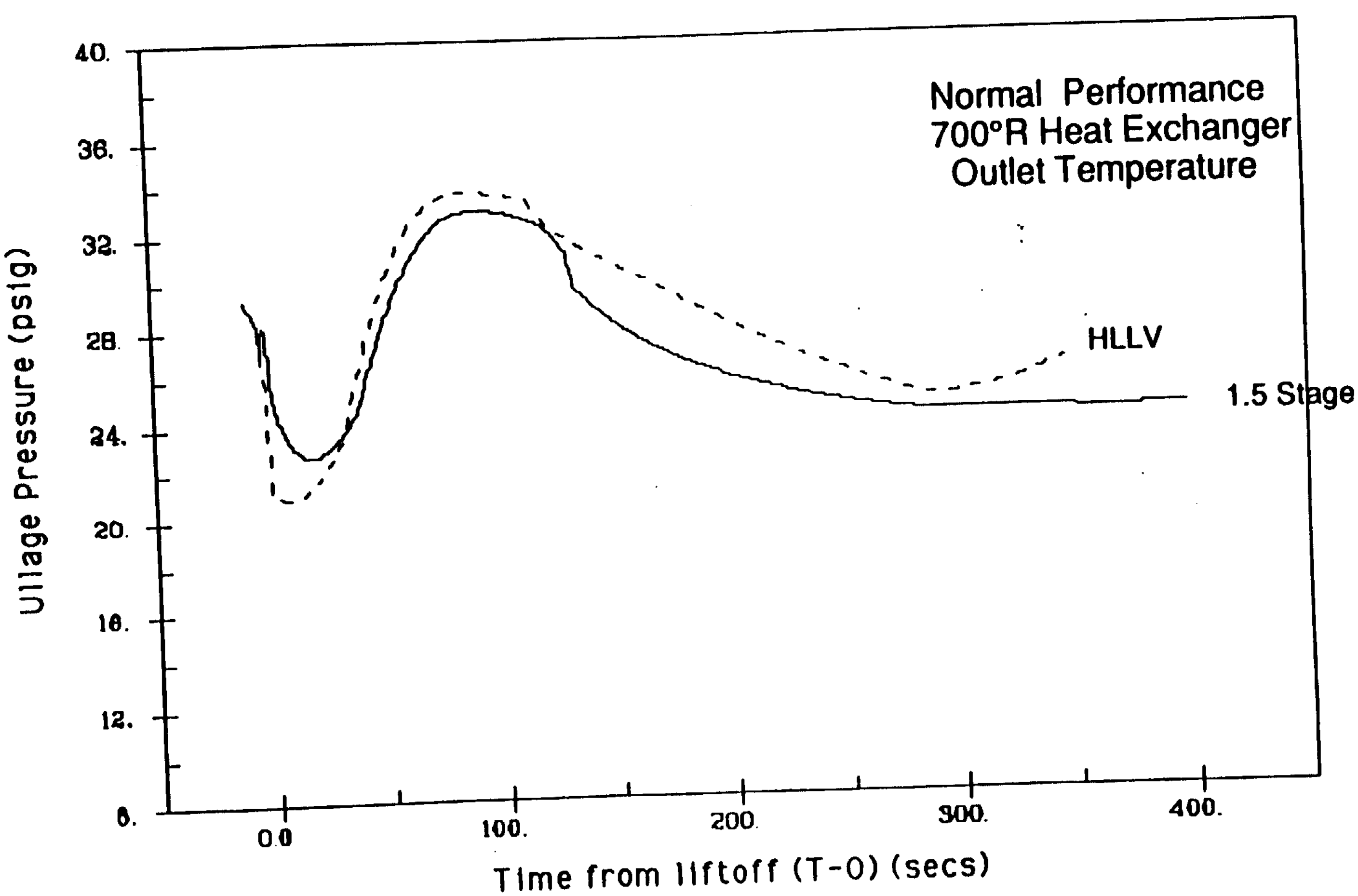
- **Con's**
  - Additional stretch of LH2 tank needed (approximately 1.5 inch)
  - Tank weight impact ~110 lbm.
  - Uncertaintly in LOX evaporation during mainstage
  - Additional LH2 tank penetrations for access and feedthrough
  - Requires engine heat exchanger
  - Additional components decrease reliability
  - System cost

Typical performance profiles are shown for constant flowrates at 700°R HEX supply temperature for the HLLV and 1-1/2 stage. Note that differential orificing was selected between Booster and Sustainer pressurant flowrates to minimize the difference in peak pressure (near BECO) and final pressure (at MECO).

An equivalent to the autogenous fixed orifice system was used for comparison purposes.

A companion analysis for engine-out performance is shown on the next page.

## LOX Tank Ullage Pressure vs Time Helium Pressurization System



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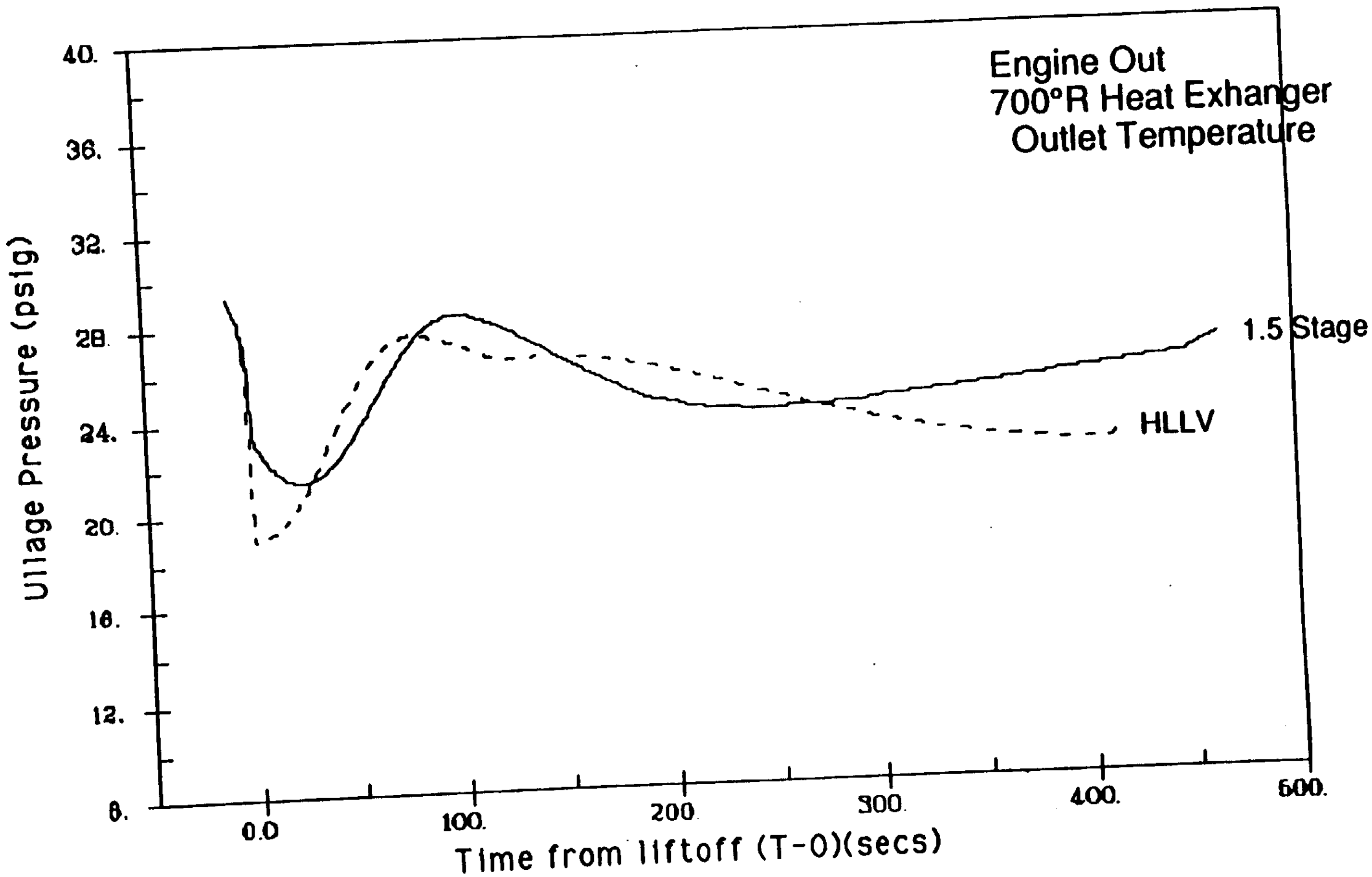
## LOX Tank Ullage Pressure vs Time
## Helium Pressurization System



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The pressurization system weights are less than those for the autogenous (GOX) system, principally due to the reduced ullage mass. For this system, a decrease in weight for an otherwise fixed launch system allows a corresponding increase in payload capability.

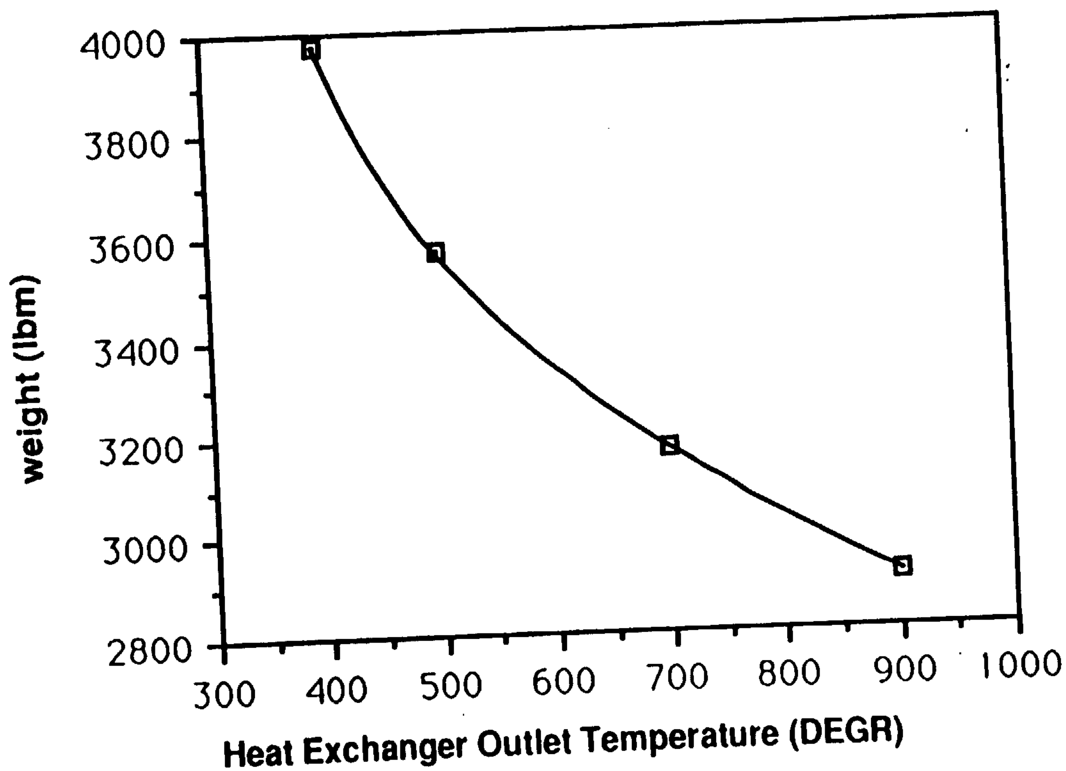
The LH2 tank stretch is to accommodate cryo-helium storage inside the tank (a volume of about 75 ft3) and associated weight maintains a comparable LH2 usable volume/mass as a trade parameter between autogenous GOX pressurization and cryo-helium storage.

An estimate of 450 lbs. LOX evaporation is based on data from Nein and Thompson,

The cost for this system is estimated to be about $1.43 M/flight.

There are more components (bottles, orifices, check valves, etc.) in a helium pressurization system than in the autogenous GOX system as can be seen by comparing the sub-system schematics. These components decrease system reliability somewhat, but prior helium pressurization systems components have performed adequately. However, one applicable failure resulted in the loss of an S-IVB stage during ground test operations when a helium bottle ruptured.

## Cryogenic Storage Helium Pressurization System Weight



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## Ambient Helium Pressurization System

- **Pro's**
  - Low system weight if helium bottles can be staged with engines
  - No additional LH2 tank penetrations

- **Con's**
  - Uncertainty in LOX evaporation during mainstage
  - Packaging of system for staging
  - Propulsion module length
  - Requires engine heat exchanger
  - Additional components decrease reliability
  - Helium cost

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An ambient helium storage system was evaluated to determine cost and performance differences with cryo-helium storage. The system shows a cost advantage over operating with cryo helium stored in the LH2 tank, and system weights for the 1-1/2 stage appear to be competitive if bottles are staged with booster engines.

Other discussion items are identical to the cryo-helium pressurization system, except for the need to regulate the helium flow interactively to accommodate the continuously variable inlet temperature to the heat exchanger as the bottles blow down. A performance analysis is not appropriate at this stage, since the results could vary greatly depending on detailed design assumptions.

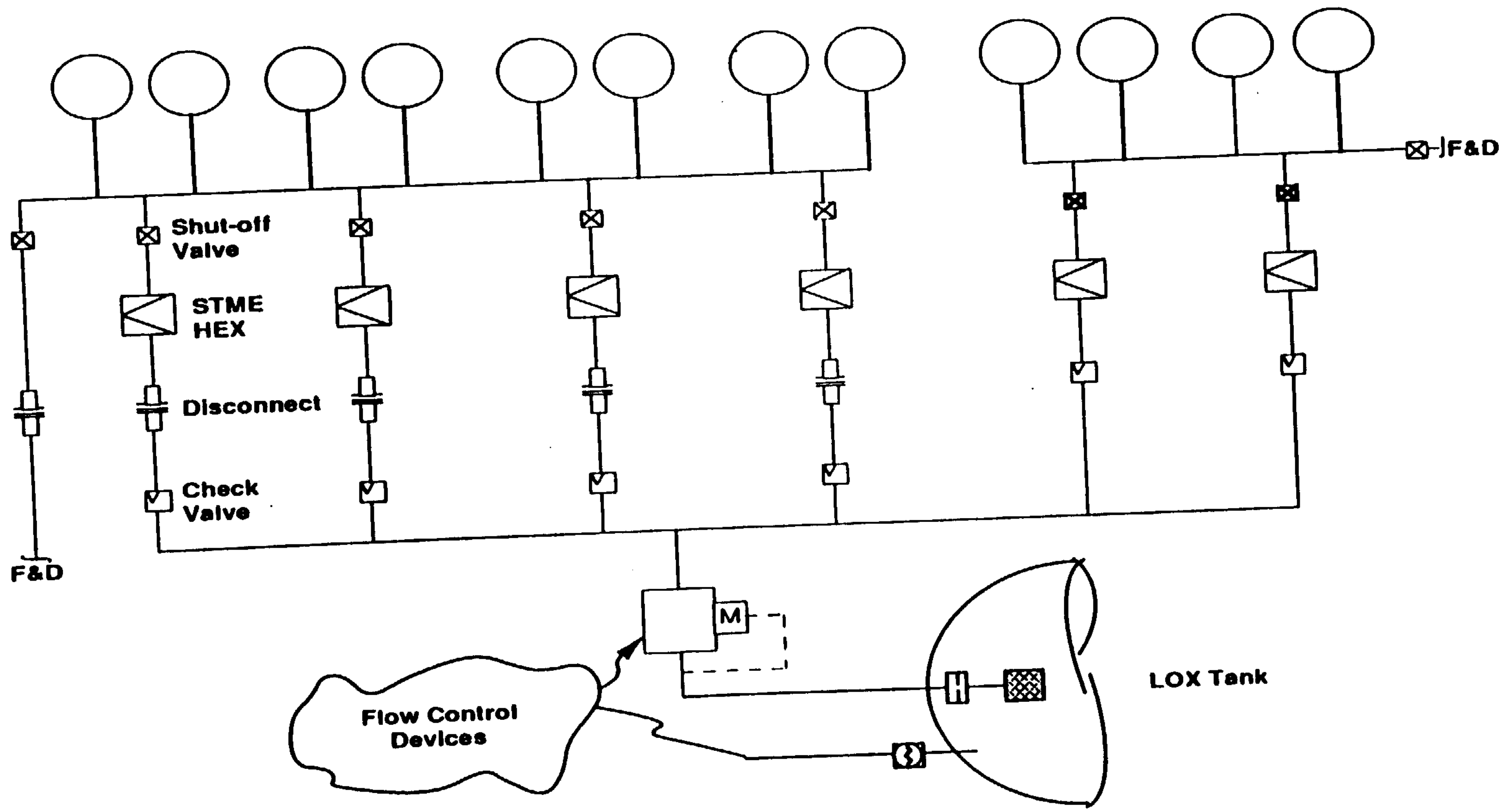
Manifolding the Booster lines and using individual shut-off valves and check valves accommodates engine-out operations.

The layout accommodates staging the bottles with the booster module.

There are a large number of possible schematic layouts, each of which has a different component count/cost/etc. The layout selected should be adequate for failure considerations. A detailed study of cost and failure considerations is required for this approach.

The motorized regulator is required to accommodate changing heat exchanger inlet temperatures as the bottles are blown down. However, a flow control scheme equivalent to the autogenous fixed-orifice system was used for comparison.

# Helium Pressurization System



# Helium Bottle Packaging

Preliminary packaging of helium bottles appears feasible. Dependent on final thrust structure, feedline arrangement and propulsion module length.

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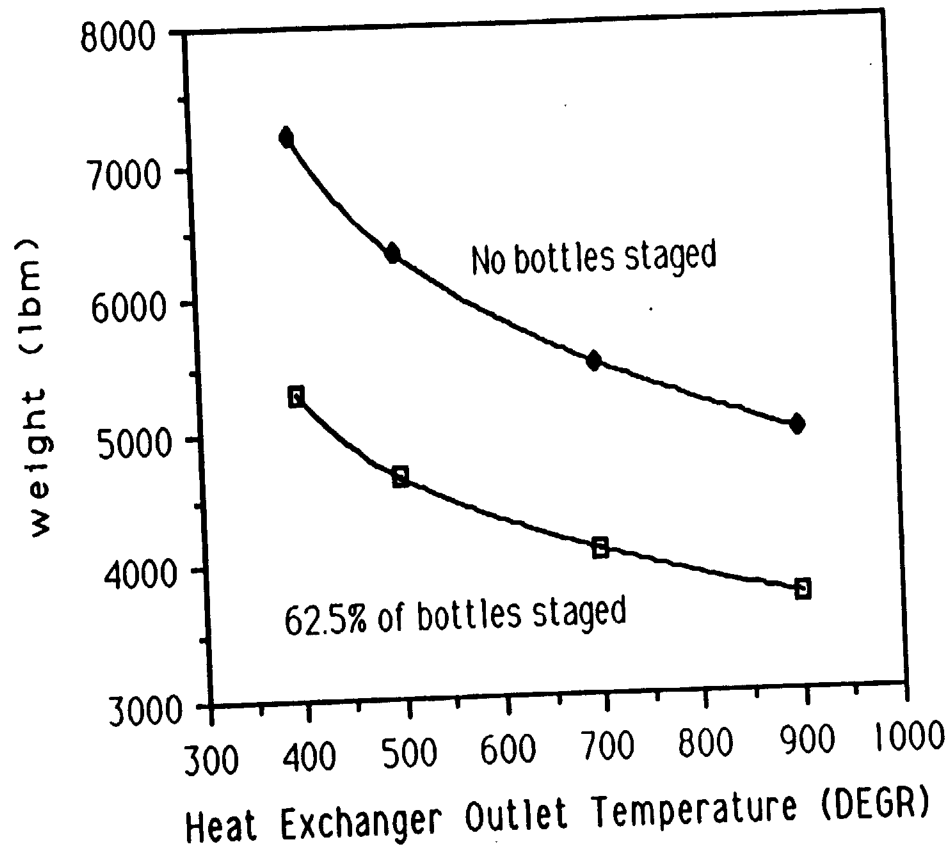
The pressurization system weight is the sum of hardware and ullage residuals at MECO with an "effective" payload impact associated with staging bottles with the booster engines. A knock-down factor of 0.43 was used, considering booster module separation at 193 seconds of 465 second flight.

The pressurant line and associated hardware weight was assumed to be approximately the same as for the autogenous system, and not variable with HEX outlet temperature.

The helium storage system weight is estimated to be 3940 lbs. and the hardware cost estimated to be $2.07 M/ flight.

## Ambient Helium Pressurization System Equivalent Weight



## Summary & Conclusions

**1.5 Stage**

- Minimum pressurization system weight is achieved using cryogenic storage helium.
- Ambient storage helium is the next best with fixed orifice autogenous being better at higher HEX temperatures.

**HLLV**

- Minimum pressurization system weight is achieved using cryogenic storage helium.
- Fixed orifice autogenous weight performance is better at higher HEX temperatures.
- Ambient helium system assumes no bottle staging and consequently will result in significant weight impact.

**Both**

- There is a potential for tank weight reduction by employing an intelligent flow control system; a time-consistent structural loads analysis is required to assess the potential payload benefits.

# Task Number 3-P-027

# STME Heat Exchanger Performance

Prepared By:
G.Platt
20 Dec, 1991

Approved By:
Z. Kirkland

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## Executive Summmary

NASA Statement of Work:

Assess current STME heat exchanger performance and possible outlet temperature increase. Assuming LOX tank pressurization system uses the STME heat exchanger for an energy source, trade system performance (residuals) against engine impacts from increased heat exchanger outlet temperature.

It was shown that for the Autogenous (GOX) pressurization system, the system using ambient helium storage, or the system using cryogenic (LH2 temperature) helium storage, the heat exchanger discharge temperature should be increased above the reference 700°R. It was found that the payload improvement due to pressurization system weight saved by increasing the temperature 200°R was 600 - 1000 lb. Tank wall temperatures were increased, as a result of the 200°R pressurant temperature increase, by 130°R at cutoff. This tank wall temperature increase is not expected to be detrimental. Greater tank wall temperature increases will require further evaluation. Heat exchanger cost per flight increases were small compared to the benefit in terms of payload improvement ($8400 for 600 - 1000 lb).

The above work was based on a 1 1/2 stage vehicle. The overall effect is expected to be similar for the HLLV.

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# Task Number 3-P-027
# STME Heat Exchanger Performance

## 1.0 Summary

It was shown that for the autogenous (GOX) pressurization system or the helium system the heat exchanger discharge temperature should be increased above the reference 700°R to at least 900° R. This would improve the payload capability of the vehicle by 600 - 1000 lbs.

## 2.0 Problem

To assess the value of increasing the STME heat exchanger outlet temperature.

## 3.0 Objective

General
To evaluate the desirability of increasing the STME heat exchanger outlet temperature.
Specific
To assess, for three candidate LOX tank pressurization systems, the desirability of increasing the heat exchanger outlet temperature from the reference 700°R.

## 4.0 Approach

The approach to performing this study was:

- To calculate a pressurization system weight, for 500, 700 and 900°R heat exchanger outlet temperatures, for each of three candidate LOX tank pressurization systems as follows:
  - Autogenous (GOX) pressurization system.
  - Helium system with helium stored in ambient temperature bottles.
  - Helium system with helium stored in bottles submerged in the liquid hydrogen tank.

Calculate the tank wall temperature for the 900°R tank inlet temperature to assure tank material integrity at the higher temperature.

## 5.0 Results

The results of this study are attached. The primary results of the study are listed below.

## 6.0 Conclusions and Recommendations

The payload capacity improvement due to pressurization weight saved by increasing the heat exchanger outlet temperature from 700 to 900°R was 600 - 1000 lb. The corresponding tank wall temperature increase was 130°R to 755°R. Greater tank wall temperature increases will require further evaluation. Heat exchanger cost per flight increases were small compared to the payload improvement ($8400 for 600 - 1000 lb.). Further work is required to define the helium pressurization control system.

## 7.0 Supporting Data

STPT fax NMO-086-20 "STME Heat Exchanger Parametrics" dated 10/04/91.

## 8.0 Attachments

Study "Task Number 3-P-027, STME Heat Exchanger Performance" dated 12/20/91.

# Task Number 3-P-027

# STME Heat Exchanger Performance

# Attachment-Detailed Data

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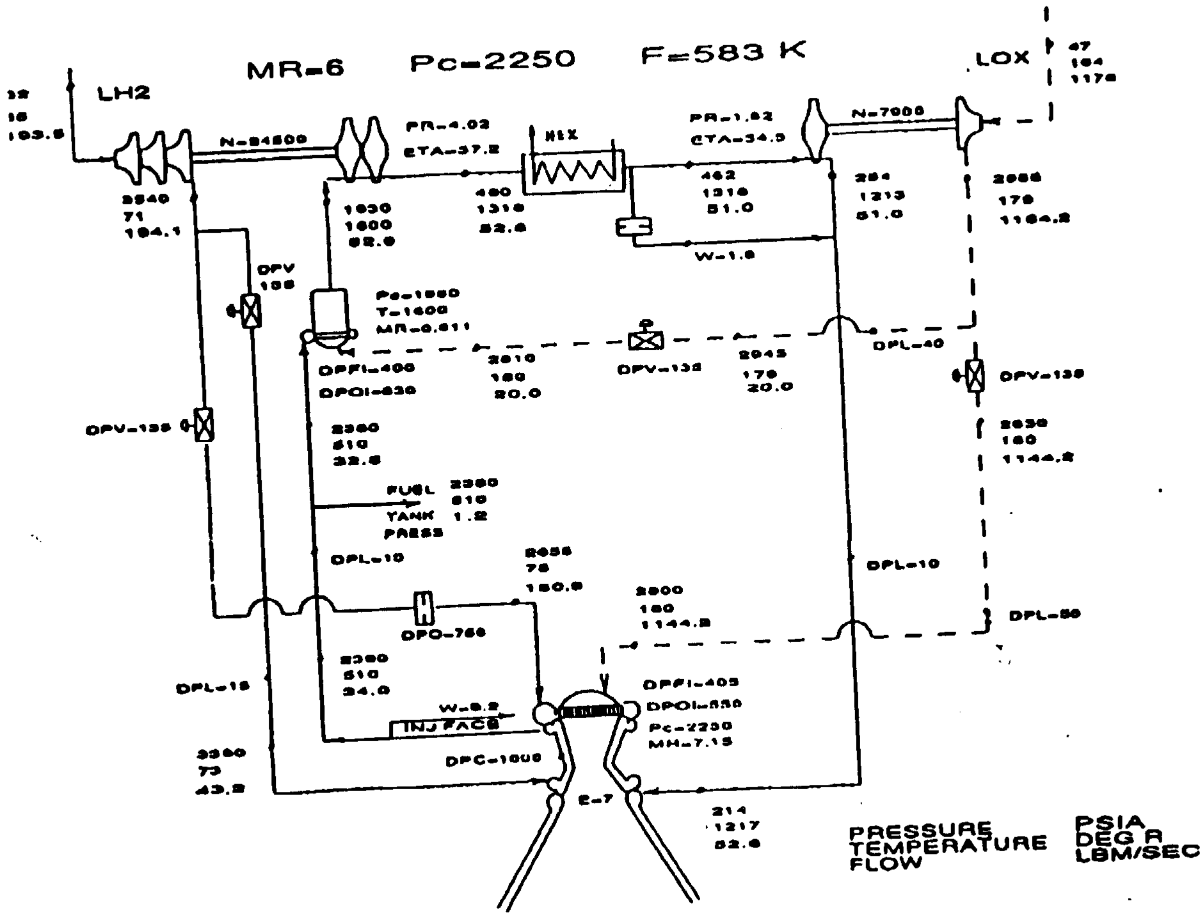
## Guidelines and Assumptions

- Did not differentiate between heat exchanger pressurant discharge temperature and tank inlet temperature.
- Heat Exchanger weight and cost data taken from STPT fax NMO-086-20 "STME Heat Exchanger Parametrics" dated 10/04/91.
- Practical upper limit for heat exchanger outlet/tank inlet mean temperature taken as 900°R based on Shuttle experience.
- Pressurization system hardware weight excluding high pressure bottles taken as 450 lb.
- Pressurization gas bottles are assumed to be available in any size required.

The facing page shows the heat exchanger location in the engine system.



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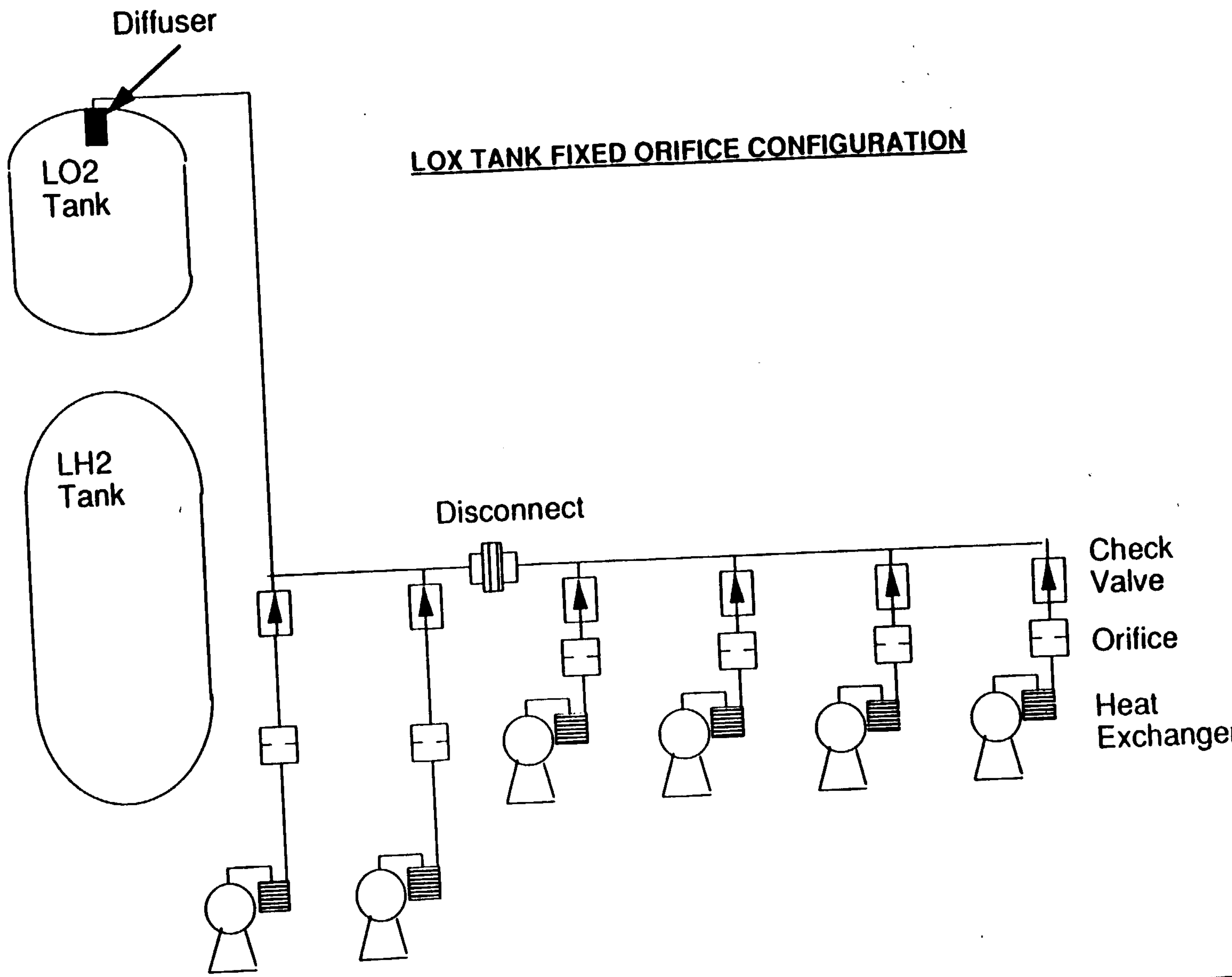
The fixed orifice pressurization system is shown in the schematic on the facing page.

## LOX TANK FIXED ORIFICE CONFIGURATION



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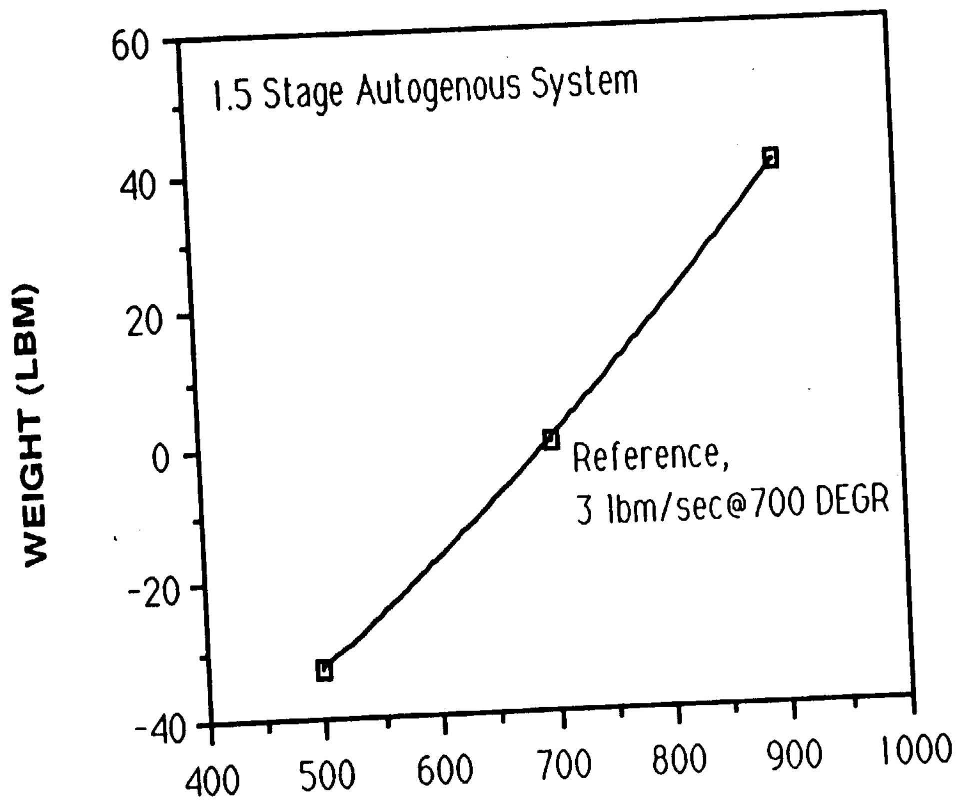
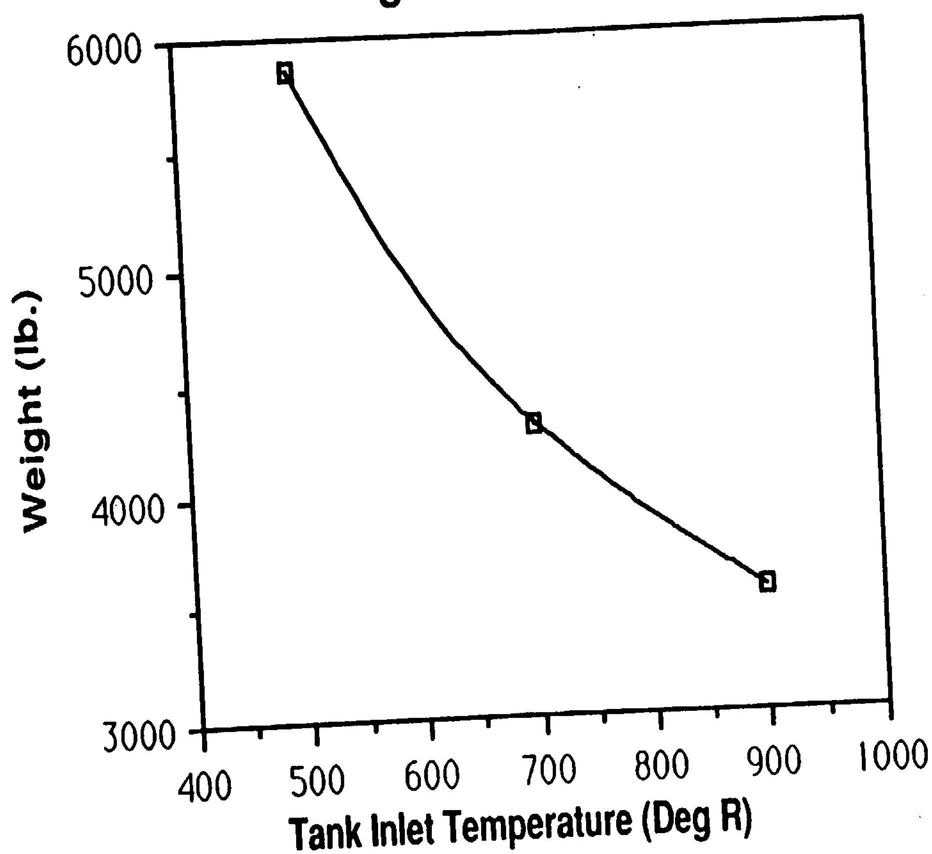
From the data supplied by STPT, the graph on the facing page was derived. The heat exchanger weight is translated into payload weight penalty. The factor used for booster weight per pound of payload weight was 0.43.

## Total Heat Exchanger Payload Weight Penalty



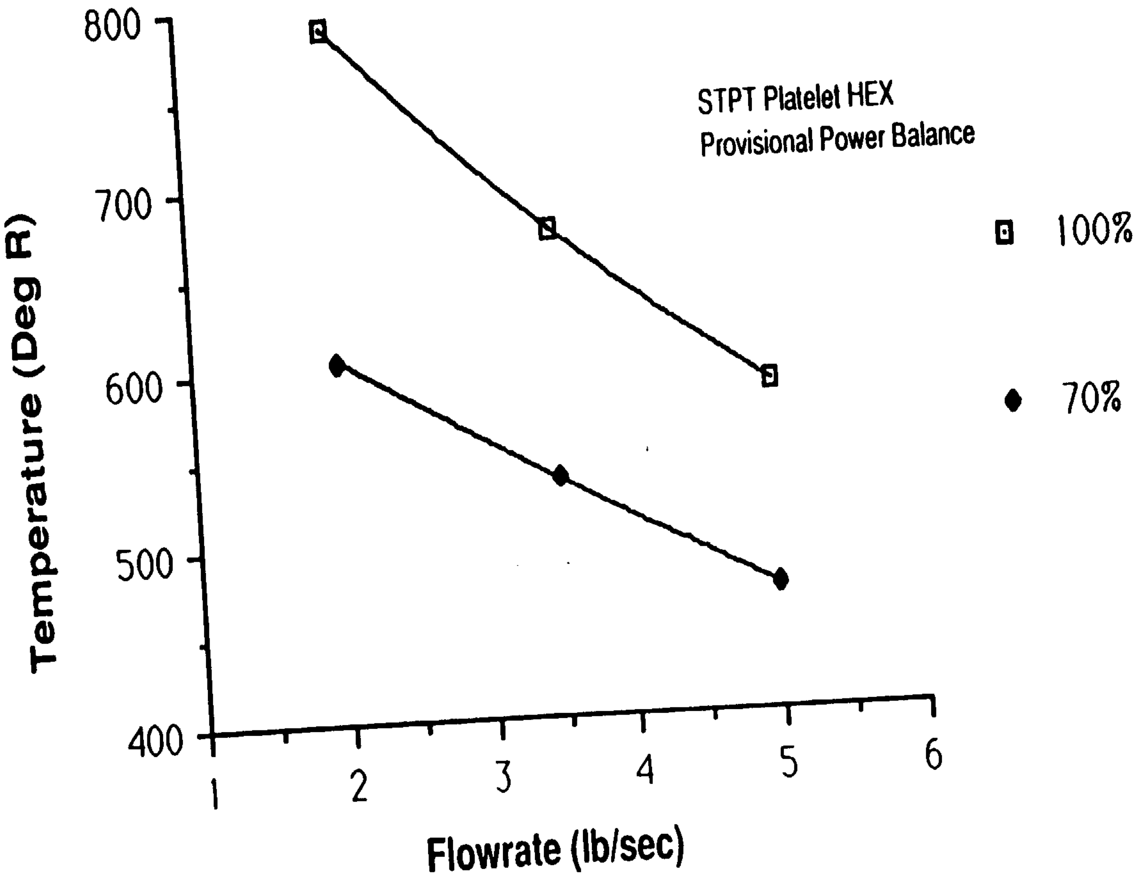
The total payload weight penalty is plotted on the facing page for the autogeneous (GOX pressurization system). Comparing this figure with the previous one, it is seen that the heat exchanger weight penalty is much smaller than the total system weight penalty.

## Autogenous Pressurization System Payload Weight Penalty



The facing page shows the results of an analysis to gain insight into the performance of the heat exchanger at two different power levels and a range of GOX flowrates. The curves were calculated for a particular heat exchanger configuration within the range supplied by the STPT. Several problems are evident from these calculations; first, the heat exchanger outlet temperature is a very strong function of power level. Therefore, the outlet temperature at 100% will have to be 25 -30 degrees higher than nominal to yield a mean as high as the nominal. Secondly, at the low gas temperatures characteristic of the 70% power level, icing of the duct may occur.

# Heat Exchanger Outlet Temperature vs. LOX-GOX Flowrate



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## Summary & Conclusions

- The heat exchanger cost and weight are not significant compared to the ullage gas weight saved by increasing heat exchanger outlet temperatures in the range considered (500 - 900°R).

- Heat exchanger performance is a strong function of the engine power level. To achieve an average outlet temperature as shown will require a higher outlet temperature at full thrust.

- Additional work is recommended to establish the maximum practical heat exchanger outlet temperature and resulting payload weight penalty and cost.

The schematic for the helium pressurization system shown on the facing page is valid for either cryogenic or ambient temperature helium storage. In the case of ambient storage, 5/8 of the storage containers would be jettisoned with the booster. For cryo storage in the LH2 tank, the total bottle weight is charged against payload.

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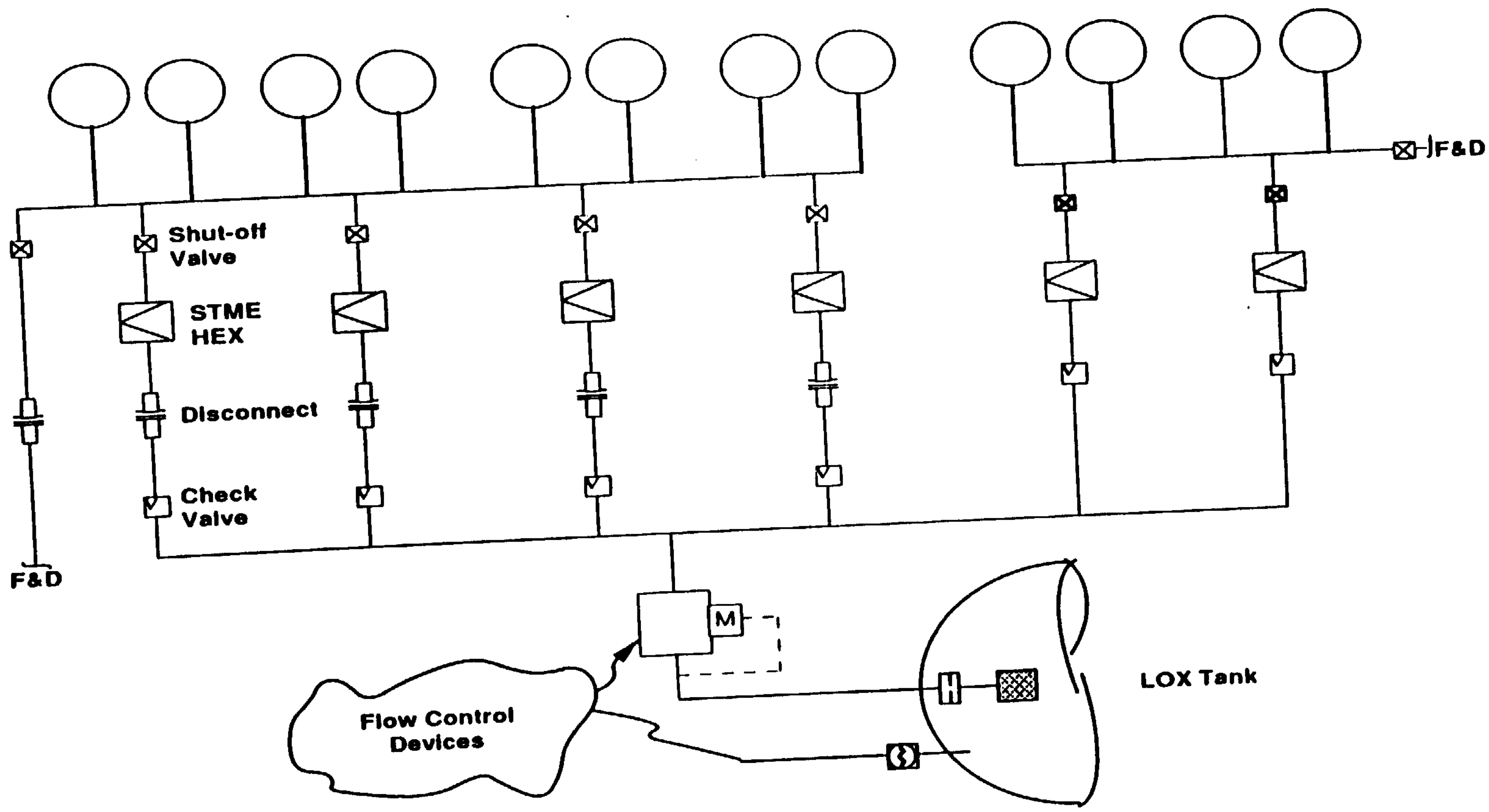
## Helium Pressurization System



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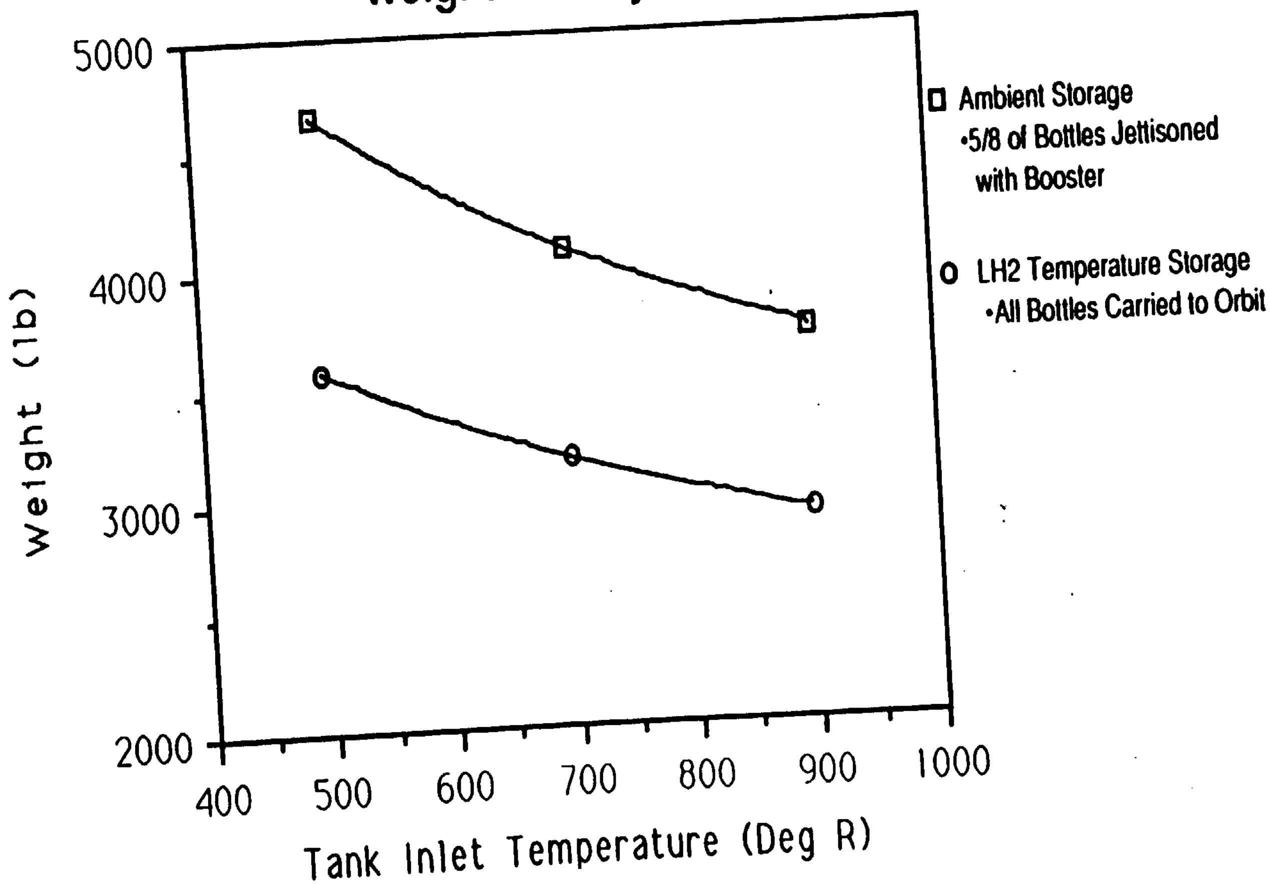
## Helium System

| | Ambient Storage | Cryo Storage |
|---|---|---|
| Initial Pressure (psia) | 4500 | 4500 |
| Final Pressure (psia) | 1000 | 1000 |
| Initial Temperature (°R) | 580 | 40 |
| Final Temperature (°R) | 400 (calculated) | 30 (calculated) |

| | |
|---|---|
| Tank Pressure (psia) | 24 at cutoff |
| Tank Pressurant Inlet Temperature (°R) | 500 to 900 |
| Resulting Heat Exchanger Flowrates (lbm/sec) | 0.35 to 0.26 |

## Helium Pressurization System Payload Weight Penalty



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## Summary & Conclusions

- The heat exchanger cost and weight are not significant compared to the ullage gas weight and storage bottle weight saved by increasing heat exchanger outlet temperatures in the range considered (500 - 900°R).
- Improvements in payload capability appear possible by further increases in heat exchanger outlet temperature.
- Additional work is required to establish the maximum practical heat exchanger outlet temperature and resulting payload weight penalty and cost.
- Further work is required to define the helium pressurization system control scheme.

# Task Number 3-P-033

# LH2 Passive Recirculation Performance Analysis

Prepared By:
G. Platt
20 Dec, 1991

Approved By:
Z. Kirkland

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## Executive Summary

Task 3-P-033, "LH2 Passive Recirculation Performance Analysis" of the National Launch System Phase B study done by MMMSS under the Shuttle C contact reads as follows: "Analysis of LH2 feed system with passive recirculation system to assess feasibility, margins and performance including an assessment of engine prestart restrictions if any." This is a report of this study and is based upon the Marshall Space Flight Center study plan dated August 5, 1991, and presented at the Technical Interchange Meeting at Marshall Space Flight Center on August 28, 30, 1991, by Danny Davis, the cognizant Panel Chairman.

Conclusions and recommendations were:

- Simple System.
- Screens make geysering correlation uncertain.
- Non-horizontal screens will not become vapor-bound.
- Saturated liquid hydrogen with 23 cubic inches/second of vapor being produced in pump expected after prepress.

Rapid warmup after start of prepress reduces NPSP 5 psi/min.
- Makes for short available hold time before depressurization-repressurization required.
- May force tank design pressure to be increased.
- May complicate operations by forcing very short engine start window before recycle required.
- Reevaluation required when engine start pressure requirement is established.

# Task Number 3-P-033
# LH2 Passive Recirculation Performance Analysis

## 1.0 Summary

The LH2 "passive recirculation" system appears to be capable of furnishing saturated, mostly liquid, hydrogen at the turbopump inlet at the start of prepressurization. The heat up rate after prepressurization of 5 psi/minute will limit hold time with tanks pressurized to 2 - 3 minutes.

## 2.0 Problem

To study and predict the performance of the reference hydrogen no bleed system.

## 3.0 Objective

General
Determine the performance of the LH2 Passive Recirculation (no-bleed) system.

Specific
Gain an understanding of the performance characteristics of the LH2 passive recirculation system. Assess geysering situation, feedline screens, and hold time.

## 4.0 Approach

The approach to performing this study was:
- Calculate engine inlet pressure with tank pressurized and unpressurized.
- Convert the engine heat flux to vapor volume.
- Calculate the rate of warmup of pump and propellant due to heating.
- Research feedline stagnation and geysering; determine performance of system relative to geysering limits.
- Calculate screen performance with regard to passing vapor.

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## 5.0 Results

The results of this study are attached. The primary results are listed below.

## 6.0 Conclusions and Recommendations

- Simple System.
- Screen makes geysering correlation uncertain.
- Non-horizontal screens will not become vapor-bound.
- Saturated liquid hydrogen with 23 cubic inches/second of vapor being produced in pump expected after prepress.

Rapid warmup after start of prepress reduces NPSP 5 psi/minute.
- Makes for short available hold time before depressurization-repressurization required.
- May force tank design pressure to be increased.
- May complicate operations by forcing very short engine start window before recycle required.
- Reevaluation required when engine start pressure requirement is established.

## 7.0 Supporting Data

NASA-CR-64-3, Contract NAS8-5418, Summary Report for the Period 1 July 1963 through 30 June 1964, "Mechanics of Geysering of Cryogenics," dated June 1964.

STPT CM No. NMO-089-17, "STME Start and Shutdown Requirements," dated 10/25/91.

STPT CM No. NMO-076-05, "STME Turbopump Heat Leaks," dated 8/29/91.

## 8.0 Attachments

Task Number 3-P-033, "LH2 Passive Recirculation Performance Analysis."

# Task Number 3-P-033

# LH2 Passive Recirculation Performance Analysis

# Attachment-Detailed Data

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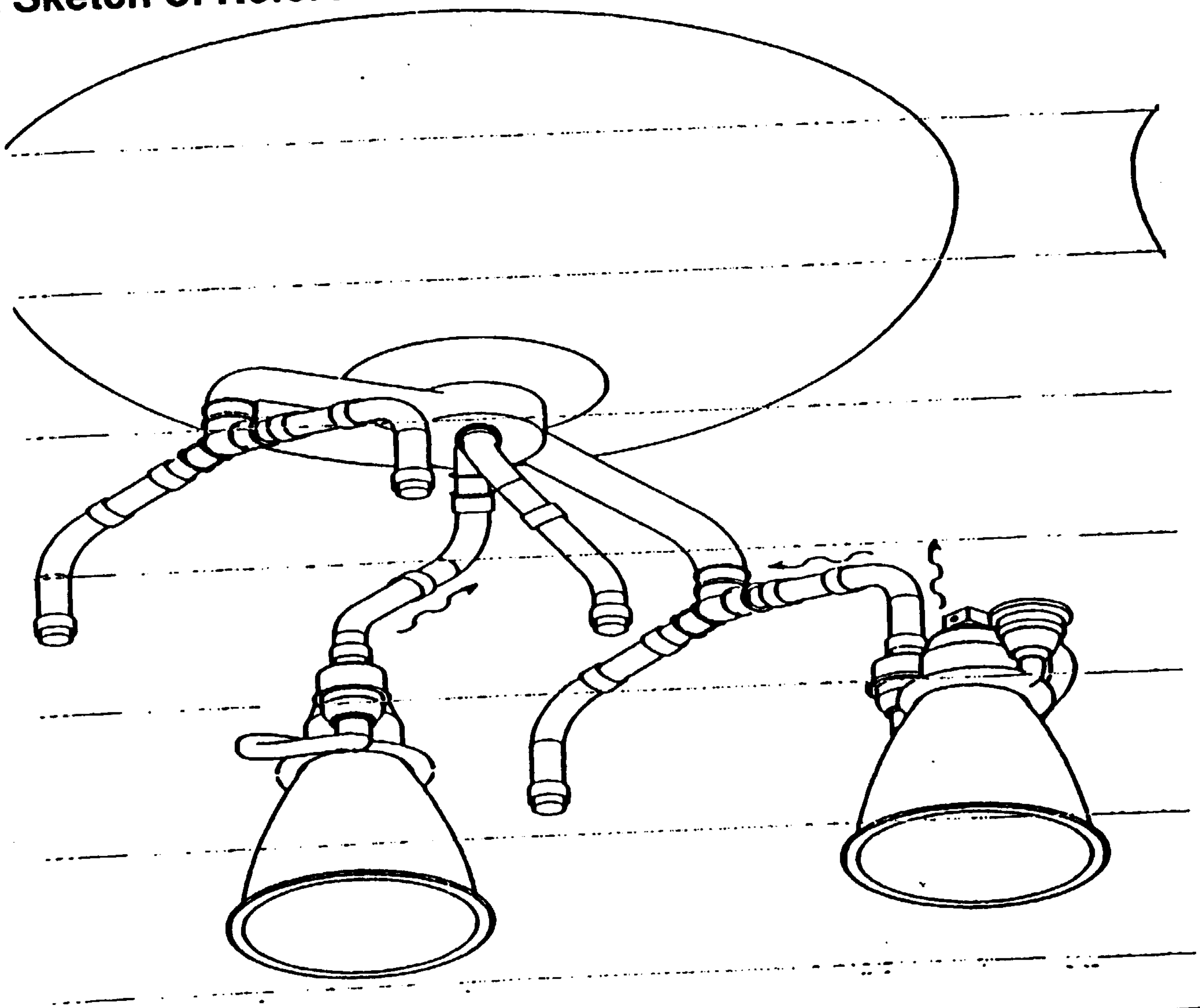
## The Reference Configuration

Our analysis was based on a Martin-Marietta version of the NASA reference feedline configuration shown on the facing page.

# NASA Sketch of Reference LH2 Passive Recirculation System





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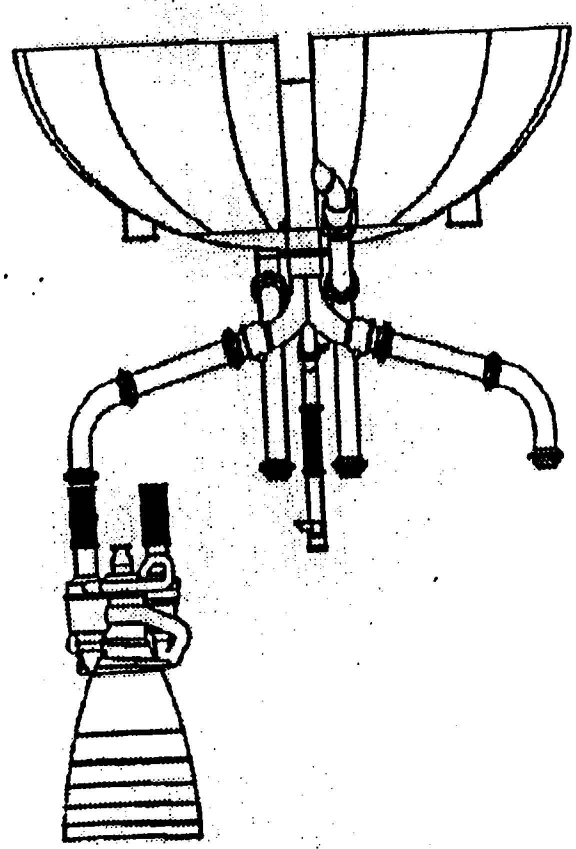
The reference configuration to the level of detail known today would provide propellant saturated at the local pressure to the engine for start. The engine would be chilled to the extent possible, as limited by its configuration and the internal flow path and heat transfer situation within the engine. The local pressure would be about three psi above tank ullage pressure; this would mean that in the best case the tank design pressure could only be reduced by three psi by providing a positive chilldown system. The real benefit of a feedline/engine chilldown system is that it does a positive feedline/engine/chill and provides for a hold after prepressurization and before engine start. If there is no engine chill system, or if it is not a positive one, the state of engine chill must await a detailed engine analysis or engine test to be known at all, and a limitation of the duration of hold after prepressurization must be accepted. This duration, per several analyses, is about one to two minutes. This time can be extended by providing a chilldown system.

## FEEDLINES
## REFERENCE NO BLEED



- RULE OF THUMB
  L/D < 10 CONVECTION OK
  L/D > 20 CONVECTION NOT ENOUGH
  (GEYSER REGION)

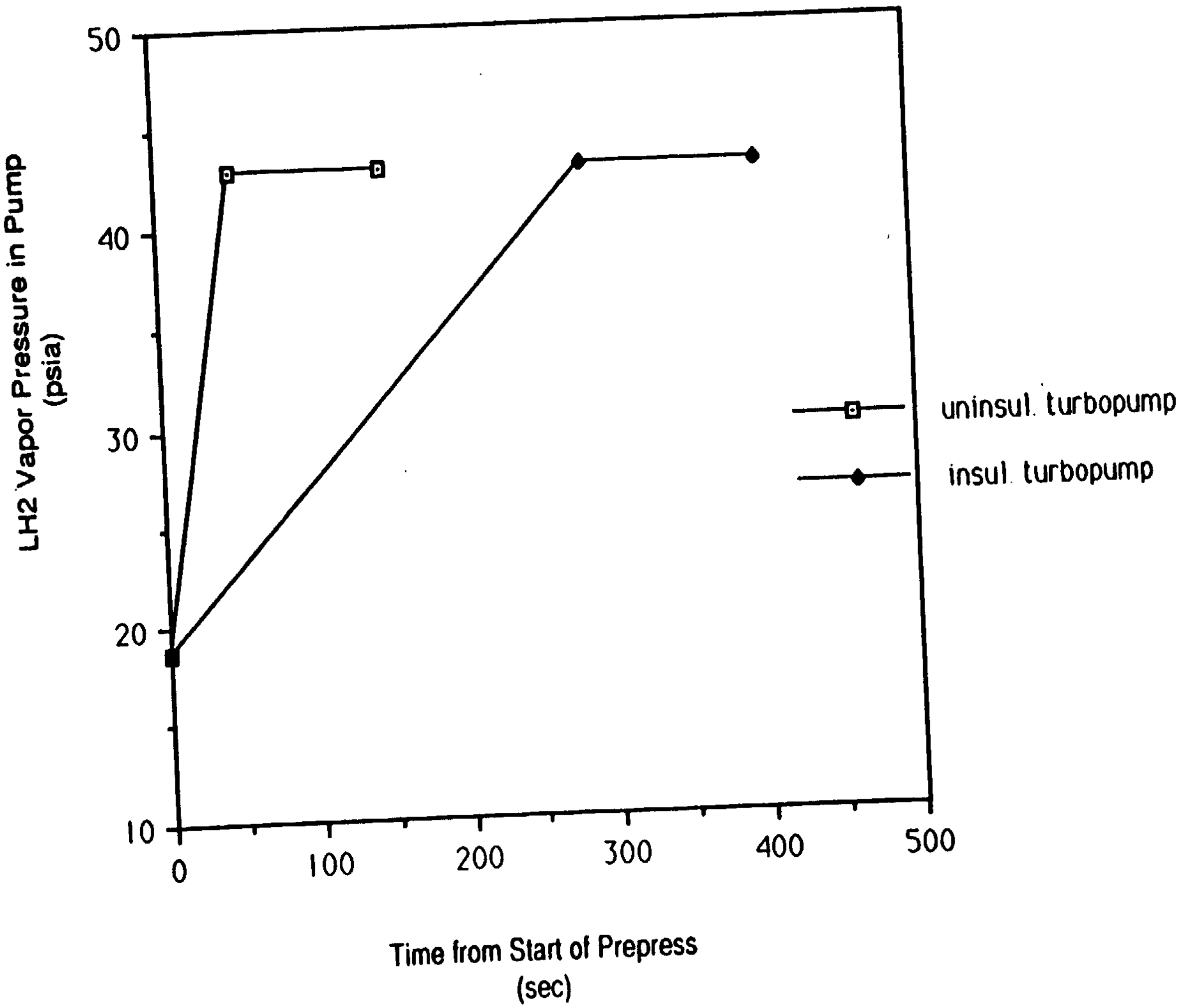
- PROBABLE DESIGN BETWEEN 10 AND 20 OR L/D > 20.

- SCREEN IN LINE WILL INHIBIT CONVECTION.
- PORES IN SHUTTLE-TYPE SCREEN WILL BE "STABLE".
- MOST VAPOR WILL PASS THROUGH AND RISE THROUGH SCREEN IF SCREEN IS NOT FLAT, HORIZONTAL.
- FEEDLINE WILL BE SATURATED. BOILOFF RATE 46 CU IN/SEC BEFORE PREPRESS 23 CU IN/SEC AFT PREPRESS.
- THERE IS NO VALID ANALYTICAL MODEL OF THE FEEDLINE WITH SCREEN.

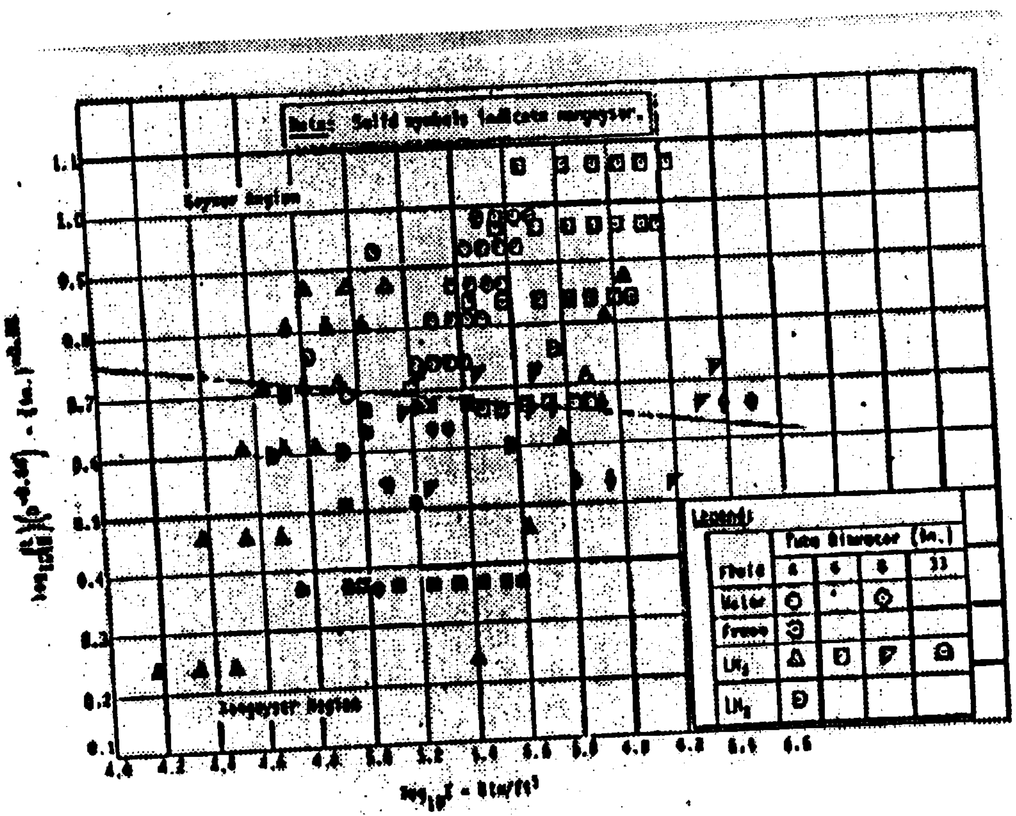
- POSSIBLE SOLUTIONS:
  - ON BOARD BLEED
  - OVERBOARD BLEED
  - RECIRC SYSTEM

The reference hydrogen no-bleed system will have a very rapid warmup rate after prepressurization.
The graphs on the facing page show the calculated warmup rates for the insulated and the uninsulated turbopump cases.

**Warmup of Propellants After Prepress.**
**LIQUID HYDROGEN**



The reference no-bleed system has an L/D of 10 to 20. For such configurations, geysering is possible. This is shown by the facing figure which comes from the research at Martin-Marietta. The likelihood of stagnation leading to geysering for a 12 inch line is considered small, however, for a smaller line or a longer line, geysering would be expected. Also, a feedline screen similar to the one in the Shuttle Orbiter feedlines is considered mandatory. This screen will inhibit convection and may lead to geysering. In a hydrogen system, geysering is not damaging. As mentioned above, even a fully saturated feedline would be acceptable, but the engine thermal condition would not be clearly understood.




$$Z = \frac{(q/A)\cdot L}{12 \propto (N_{PR})^{1/3}}$$

| | L = 20' - 240" | | |
|---|---|---|---|
| | 8" | 10" | 12" |
| $\left(\frac{L}{D} \bullet D^{-.68}\right)$ | 7.3 | 5.02 | 3.7 |
| $\log_{10}\left(\frac{L}{D} \bullet D^{-.68}\right)$ | .86 | .7 | .568 |

$q/A = 60\ B/Hr\text{-}ft^2$

| | LOX | $LH_2$ |
|---|---|---|
| | $Z = 1990 \bullet L$ | $768 \bullet L$ |
| L = 20 | $Z = 477600$ | 184320 |
| $\log_{10}$ | $Z = 5.67$ | 5.26 |



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## Summary & Conclusions

- Simple System.
- Screens make geysering correlation uncertain.
- Non-horizontal screens will not become vapor-bound.
- Saturated liquid hydrogen with 23 cubic inches/second of vapor being produced in pump expected after prepress.

Rapid warmup after start of prepress reduces NPSP 5 psi/minute.

- Makes for short available hold time before depressurization-repressurization required.
- May force tank design pressure to be increased.
- May complicate operations by forcing very short engine start window before recycle required.
- Reevaluation required when engine start pressure requirement is established.

# Task Number 3-P-034

# LH2 Bleed/Recirculation Study

Prepared By:
G. Platt
20 Dec, 1991

Approved By:
Z. Kirkland

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## Executive Summary

The NASA Statement of Work for this study reads as follows:

Assess a no-bleed vs. bleed or recirculation system for the LH2 feed system considering at a minimum operability, reliability, propulsion module layout and tank stretch, weight, and cost.

- Reference No-Bleed System will result in saturated LH2 in feedline and engine pump with vapor in engine pump and dry lines downstream of engine pump.
  Convection path complicated by screen.
  Analytical model and test program to anchor analytical model required.
  Warm-up after prepressurization increases saturation pressure 5 psi/minute. Would require depressurization of tank, repressurization for very short hold. (Engine start pressure not yet defined.)
- On-Board Bleed has low flowrate, hydrogen quality in turbopump will be poor (80% vapor by volume). If this is satisfactory, would allow improvement in hold after prepress relative to no-bleed system.
  Test program required.
  Slight improvement in performance compared to no bleed.
- Overboard bleed has adequate performance after prepressurization. Hold time limited due to loss of LH2 at 1.2 lb/sec per engine.
  Hardware complexity a disadvantage.
  SSME manufacturer uses this system, in principle, for single engine tests.
  Should be retained for further study.
- Backward recirculation did not appear advantageous.
  Provides good engine/pump chill.
  Introduces large volume of vapor into feedlines.
  Hardware complexity a disadvantage.

- Forward recirculation:
  Predictable, good experience with systems.
  Hardware complexity a disadvantage.
  Together with overboard bleed, provides best engine/pump chill.
  Provides best performance (best chill, no hold time limitation).

# Task Number 3-P-034
# LH2 Bleed/Recirculation Study

## 1.0 Summary

Four alternates to the reference no-bleed system were studied to establish their performance characteristics and other attributes. Forward recirculation and the overboard bleed to the facility were both superior to the reference system.

## 2.0 Problem

Assess a no-bleed vs. bleed or recirculation system for the LH2 feed system considering at a minimum operability, reliability, propulsion module layout and tank stretch, weight, and cost.

## 3.0 Objective

General
To compare candidate bleed systems with the no-bleed system for the LH2 feed system.
Specific
Compare performance, predictability, repeatability, precedence, engine impact, feed system impact, engine test impact, potential future change, operational efficiency, potential hazard, and hardware complexity of candidate bleed system concepts against the reference no-bleed system.

## 4.0 Approach

First, the candidate systems were identified and the performance of each was predicted. Then the systems were compared with each other and the reference with regard to the attributes listed in 2, above.

## 5.0 Results

The results of this study are attached. The primary results are listed below.

## 6.0 Conclusions and Recommendations

- Reference No-Bleed System will result in saturated $LH_2$ in feedline and engine pump with vapor in engine pump and dry lines downstream of engine pump.
  Convection path complicated by screen.
  Analytical model and test program to anchor analytical model required.
  Warm-up after prepressurization increases saturation pressure 5 psi/minute. Would require depressurization of tank, repressurization for very short hold.
- On-Board Bleed has low flowrate, hydrogen quality in turbopump will be poor (80% vapor by volume). If this is satisfactory, would allow improvement in hold after prepress relative to no-bleed system.
  Test program required.
  Slight improvement in performance compared to no bleed.
- Overboard bleed has adequate performance after prepressurization. Hold time limited due to loss of $LH_2$ at 1.2 lb/sec per engine.
  Hardware complexity a disadvantage.
  SSME manufacturer uses this system, in principle, for single engine tests.
  Should be retained for further study.
- Backward recirculation did not appear advantageous.
  Provides good engine/pump chill.
  Introduces large volume of vapor into feedlines.
  Hardware complexity a disadvantage.

- Forward recirculation:
  Predictable, good experience with systems.
  Hardware complexity a disadvantage
  Together with overboard bleed, provides best engine/pump chill.
  Provides best performance (best chill, no hold time limitation).

## 7.0 Supporting Data

3-P-033, "LH2 Passive Recirculation Performance Analysis."

## 8.0 Attachments

Task Number 3-P-034, LH2 Bleed/Recirculation Study "LH2 Passive Recirculation Performance Analysis."

# Task Number 3-P-034

# LH2 Bleed/Recirculation Study

# Attachment-Detailed Data

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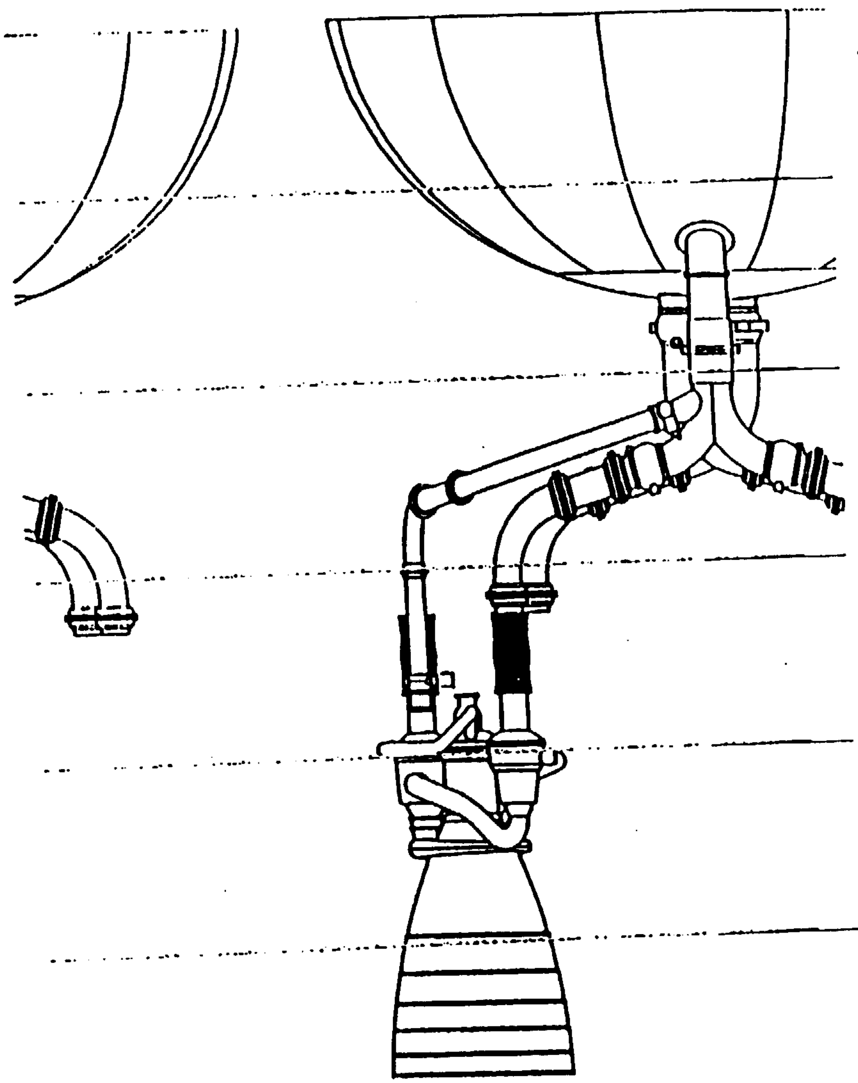
The problem of LH2 feedline and engine conditioning during prelaunch has been solved for different engines and feed systems in different ways, however, there has always been a chill of the LH2 turbomachinery and the thrust chamber. The STME has baselined a zero chill system, and has no specific requirements to which a chill system should be designed. Whether the STME can be successful in developing a zero chill system is not known, therefore, it was considered necessary to consider several possible methods of chilling the STME prior to start. These methods have different degrees of potential effectiveness. The performance of each was predicted as applied to a reference configuration supplied by NASA, shown on the facing page, and is compared to the reference.



**Feedlines Reference No Bleed**

•Rule of Thumb
L/D < 10 Convection OK
L/D > 20 Convection Not Enough (Geyser Region)

•Probable Design Between 10 and 20 or L/D > 20

•Screen In Line Will Inhibit Convection
•Pores in Shuttle-Type Screen Will Be "Stable"
•Most Vapor Will Pass Through and Rise Through Screen if Screen is Not Flat, Horizontal
•Feedline Will Be Saturated. Boiloff Rate 46 In3/Sec Before Prepress 23 In Cu/Sec after Prepress
•There is No Valid Analytical Model of the Feedline With Screen

•Possible Solutions
•On Board Bleed
•Overboard Bleed
•Recirc System

## Chilldown Systems

The candidate engine/feedline chilldown systems were evaluated on the basis of the attributes shown on the facing page.

All chilldown systems were assumed to have a 60 Btu/hr-ft2 heat leak if insulated and 600 Btu/hr-ft2 heat leak if uninsulated.

## ATTRIBUTES CONSIDERED IN EVALUATING SYSTEMS

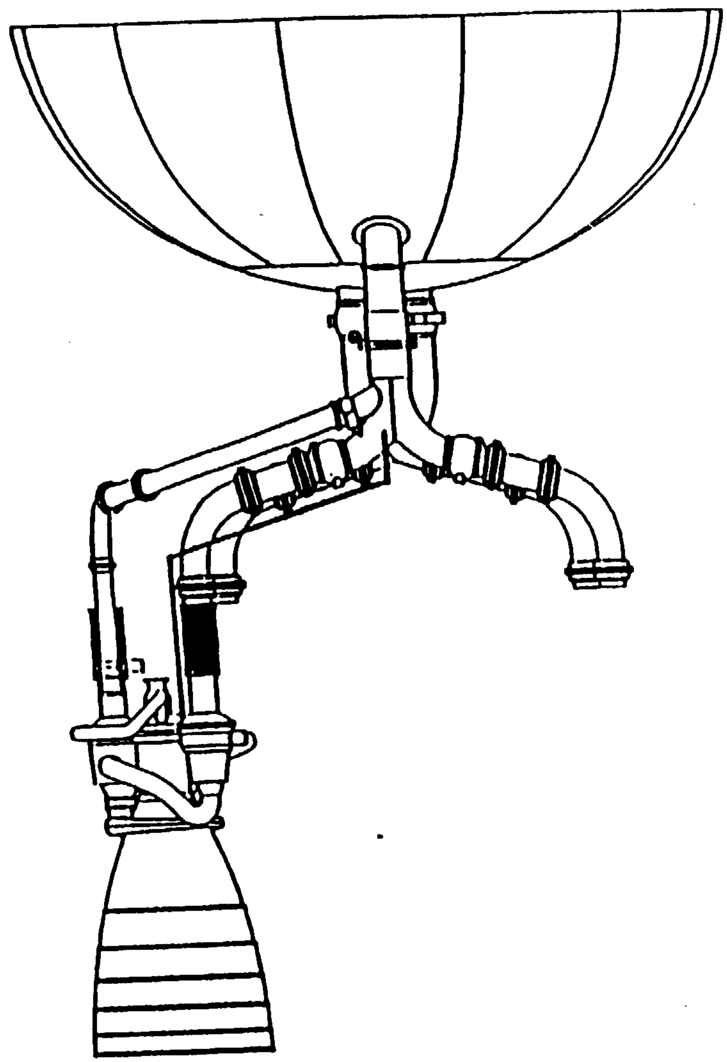
- PREDICTABILITY
- REPEATABILITY, ENGINE TEST TO VEHICLE
- PRECEDENCE
- IMPACT ON ENGINE DESIGN
- IMPACT ON FEED SYSTEM/ENGINE INSULATION
- IMPACT ON ENGINE TEST
- POTENTIAL FOR REQUIRED FUTURE CHANGE
- OPERATIONAL EFFICIENCY
- HAZARD INTRODUCED
- HARDWARE COMPLEXITY

## The On-Board Hydrogen Bleed

The on-board hydrogen bleed was evaluated because of its simplicity. It has no ground interface and does not vent to the atmosphere. Based on the Martin-Marietta layout shown on the next figure, the available head would be approximately 12 feet or a maximum of 0.36 psi. The return line was assumed to be one inch in diameter and reenter the feedline just below the disconnect. The calculated flowrate would be less than 0.12 lb/sec per engine at the calculated heat load. The thermodynamic quality in the pump would be greater than 0.08 or 80% vapor by volume. For a doubled heat load, the flowrate would be less than 0.075 lb/sec with the quality in the turbopump and the return line greater than 0.13, or 85% vapor by volume. With a doubled return line flow capacity and the calculated heat leak, the volumetric quality would be approximately 0.6. This large volume of vapor would enter the feedline at the elbow where the two feedlines split, and would flow up the 17 inch line into the tank. The vapor would tend to condense at the time the tank is prepressurized; the temperature difference to drive the condensation would be 8 deg R. With this system, the hold time after prepressurization would not be extended significantly as compared to the reference system.

The on-board bleed scheme is considered poor from a predictability standpoint. This principle, natural circulation, has never been applied to the design of a hydrogen system. Similarly, the system performance is not expected to be repeatable from engine test to vehicle unless the feed system is virtually identical in the two cases including duct and line wall thicknesses and thermal response rates.

The system adds an engine bleed valve. A very good insulation of the turbopump and feedline would be required. This might present a maintenance problem. There would be a high potential that a future change would be required to make the system work. The system has no ground interface and introduces few joints which might leak, so it would not be expected to introduce much hazard. Similarly the system is simple, involving only hydrogen bleed valves and small lines.



## On Board Hydrogen Bleed

- Requires No Disconnects
- Requires Engine Hydrogen Bleed Valve
- Available Head is Approx. 12 Feet or a Maximum of 0.36 psi
- Flowrate is Less than 0.12 lb/sec Per Engine at Calculated Heat Load. Quality is Greater Than 0.05 (70% Vapor by Volume). For Doubled Heat Load, Flowrate is Less Than 0.075 lb/sec With Exit Quality Greater than 0.13 (85% Vapor by Volume)
- With Shortened Aft Compartment (Stretched Hydrogen Tank) Performance Would Be Reduced

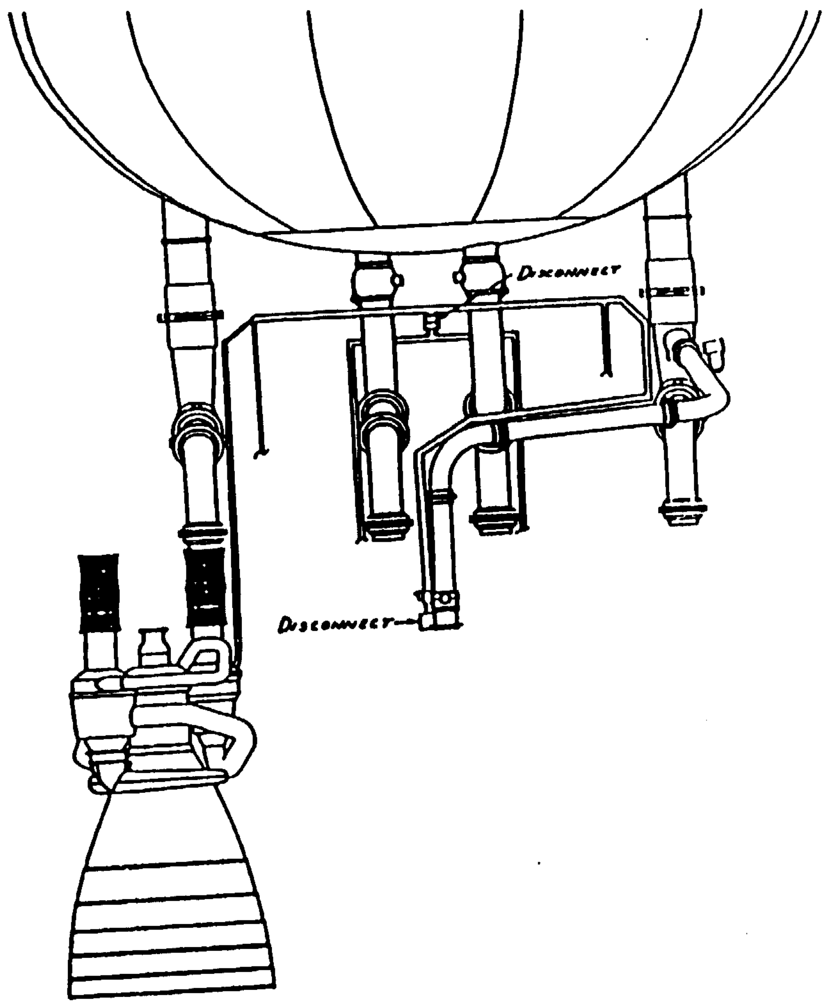
## The Overboard Bleed to the Facility

The scheme is shown in the next figure. It has more capacity than the on-board bleed because the full head of the hydrogen on board as well as the vent valve and vent line pressure drop are available to drive the flow, which must overcome only the vent system pressure drop. Because of this higher head, the system performance is more predictable than the on-board bleed, and more repeatable from engine test to flight vehicle configuration than the no-bleed or the on-board bleed. Also, the available hold time after prepressurization would be extended, limited by the amount of propellant lost overboard and the heating of the bulk of the hydrogen in the tank. The insulation requirements would not be severe because of the relatively high flowrate that could be obtained. The precedence for the overboard bleed was the RL-10 engine which was used for the second stage application (the S-IV). It was bled in flight during first stage burn through long vent stacks which carried the hydrogen to the aft end of the first stage (the S-I). In this case the system had the full tank pressure plus the head of the fluid to drive the flow. The potential for a required future change was considered fairly large because of the lack of recent experience with similar systems for flight. The facility hydrogen disposal system would have to accommodate the larger hydrogen flowrate of the bleed plus tank vent rather than the tank vent alone.

This system would require an engine bleed valve. It is felt that the impact on engine test would be small, since this kind of a bleed has been used in the past for engine development tests.

The system would introduce a moderate hazard, since the added disconnects would add leak sources. The number of added disconnects would depend on the design, but at least two would be required. The hardware complexity added would be engine bleed valves, required for all concepts, the disconnects discussed above, and small lines on board.

**Hydrogen Overboard Bleed**




- Bleeds From Engines Are Manifolded and Directed to Ground Disconnect
- Disconnects Must be Provided for Engine Lines (Inboard Engines if Disconnect on Same Plate as Fill, If F&D is Jettisoned)
- Requires Engine Bleed Valve, Probably on Gas Generator Supply Line
- Can be Manifolded to Minimize Number of Inflight Disconnects
- Approx. 2.8 psi Available to Drive Flow (Assumes 1 psi Ground Disposal System Pressure Drop)
- Provides Approx 0.1 lb/sec Flow to Chill Each Engine at Exit Quality of 0.1 (80% Vapor by Volume) with Calculated Heat Load
- Provides High Flowrate (1.2 lb/sec) After Prepress.
- Allows Extended Hold After Prepress. (Limited by Allowable Propellant Loss)

## Backward Recirculation

Backward recirculation was considered for the Saturn S-II and Saturn S-IVB stages. Performance calculations were run utilizing a computer program that was developed for Saturn and verified on Saturn and on the Shuttle program.

The backward recirculation system is simpler than forward recirculation as used on Shuttle in that prevalves are not required. The system was calculated for one inch lines, since they would not require gimbals, but could utilize the simpler flex lines. The allowable hold after prepressurization would be increased compared to the baseline. The major disadvantage was that large amounts of vapor were introduced into the feedline. This is not necessarily a problem, but relies on the vapor recondensing during prepressurization. This recondensation is nearly unpredictable, and tests would be required to assess its acceptability.

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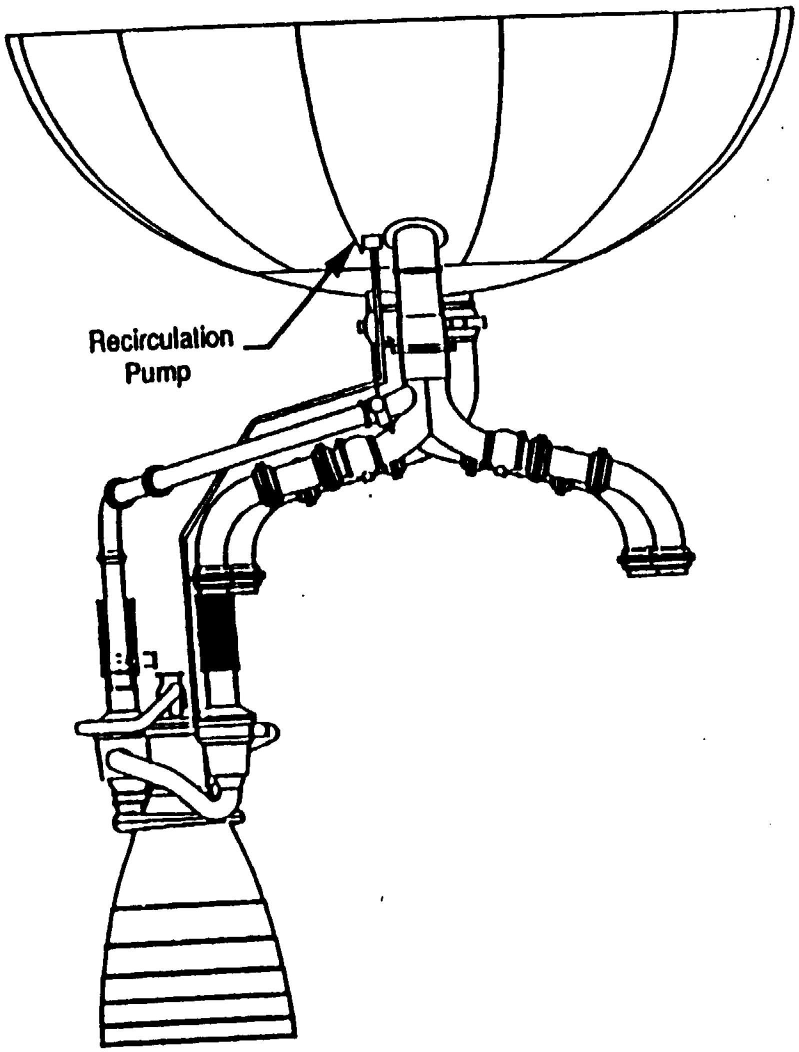
The backward recirculation system was judged to have fair to good predictability, because of the vapor in the feedline. The performance of the flow in the pump and lines was thought to be highly predictable and repeatable, the pump and small line would perform the same on engine tests and on the vehicle. An engine bleed valve would be required. Since the relatively large flowrate of 1 lb/sec would be assured, only moderate feedline and engine turbopump insulation performance would be required. The impact on engine test would be moderate, but to allow correct assessment of engine performance as it would be on the vehicle, the recirculation pump and recirculation line would have to be installed on the engine test facility.

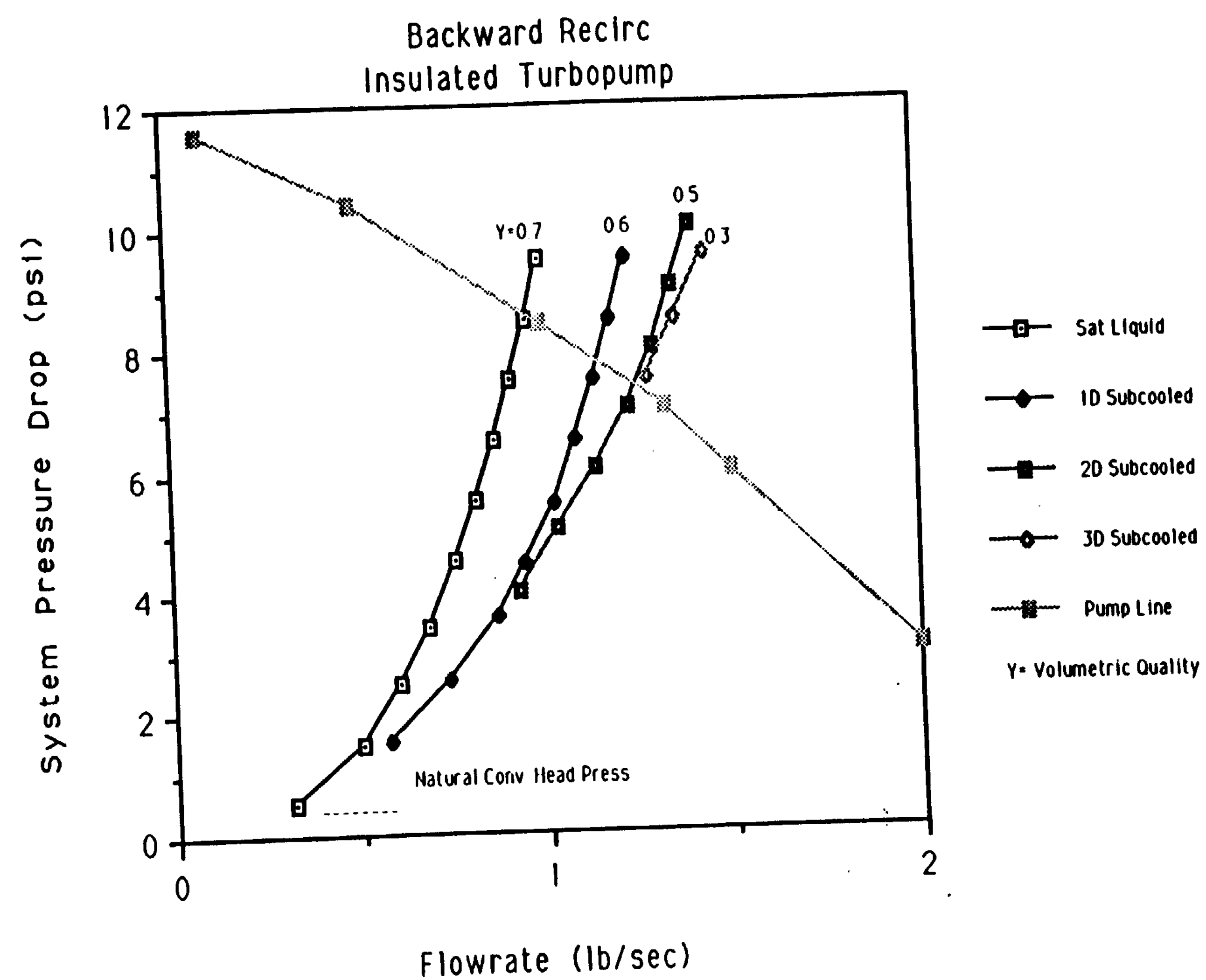
The potential for future change would be fairly large because of the large volume of vapor in the feedline. As to operational efficiency, the system is complicated by the addition of recirculation pumps. These pumps have been very reliable, except that a connector problem surfaced several times on the Shuttle. It is reasonable to assume that this problem has now been corrected. Also, as on any chilldown system, it is assumed that temperature interlocks will be required. The hazard introduced is considered moderate, in that leakage sources have been introduced, and four onboard disconnects have been added.




## BACKWARD HYDROGEN RECIRCULATION

- STANDARD SHUTTLE RECIRC. PUMP PUMPING BACKWARDS THROUGH THE ENGINE SYSTEM AND FEEDLINE.
- REQUIRES ENGINE BLEED VALVE ON GAS GENERATOR SUPPLY LINE.
- REQUIRES DISCONNECTS IN RECIRCULATION LINES.
- OPERATES WITH PREVALVES OPEN, RETURN HYDROGEN FLOW IN MAIN FEEDLINES.
- UTILIZES SAME RECIRCULATION PUMP AS SHUTTLE.
- ACHIEVES HIGH FLOWRATES EVEN WITH ONE INCH RECIRCULATION SYSTEM LINES.
- DISCONNECTS REQUIRED FOR OUTBOARD LINES.
- INSENSITIVE TO HEAT LOAD.
- LARGE VOLUME OF GASEOUS HYDROGEN INTRODUCED INTO MAIN FEED LINES.

The following figures show the backward recirculation performance characteristics. With saturated liquid at the pump discharge the flowrate at the point where the pressure drop versus flowrate curve intersects the pump performance curve is between 0.9 and 1.0 lb/sec. This is the point at which the system will operate, and at this point the vapor fraction of the volume flowing at the recirculation line exit is 0.7. Similarly, with greater subcooling, the flowrate increases to approximately 1.2 lb/sec and the vapor volume decreases to 30% at 3 deg F of subcooling. Since the head is only approximately 3 psi at the tank bottom, we can expect no more than 1 deg of subcooling. The pump work will add less than 1 psi to the vapor pressure, or about 0.2 deg F. From this, the system performance will be between the saturated and the 1 deg subcooled curves, depending on the liquid level in the tank. When the system heat load is doubled and the turbopump is left uninsulated, the system performance changes only slightly. This shows that the system is not sensitive to the insulation. The turbopump would have 4.36 Btu/sec heat leak for the uninsulated case and 0.74 Btu/sec for the insulated case. These data were supplied by Pratt and Whitney to DeWitt Westrope on August 29, 1991 (CM No. NMO-077-05).



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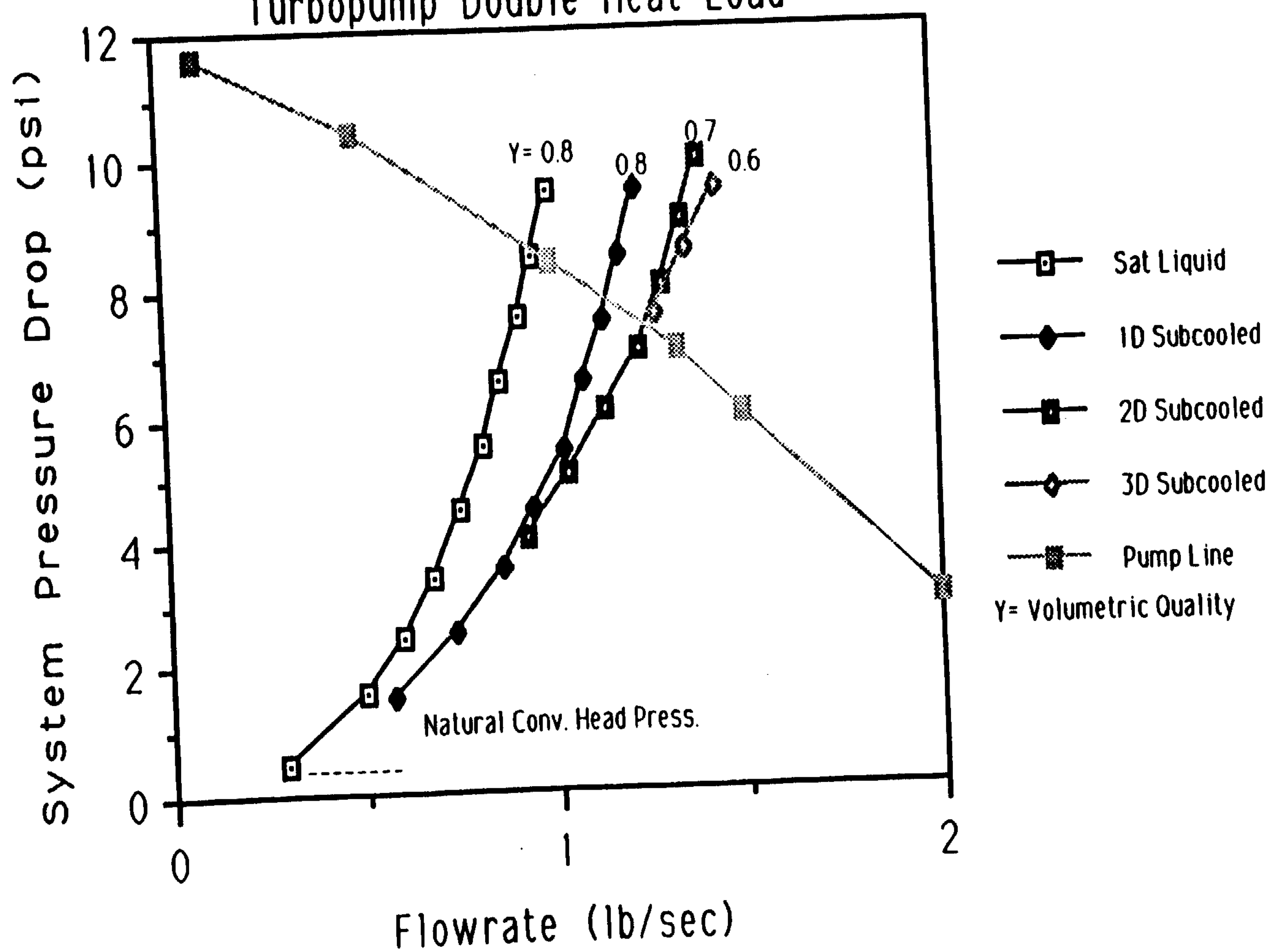
Backward Recirc Uninsulated
Turbopump Double Heat Load



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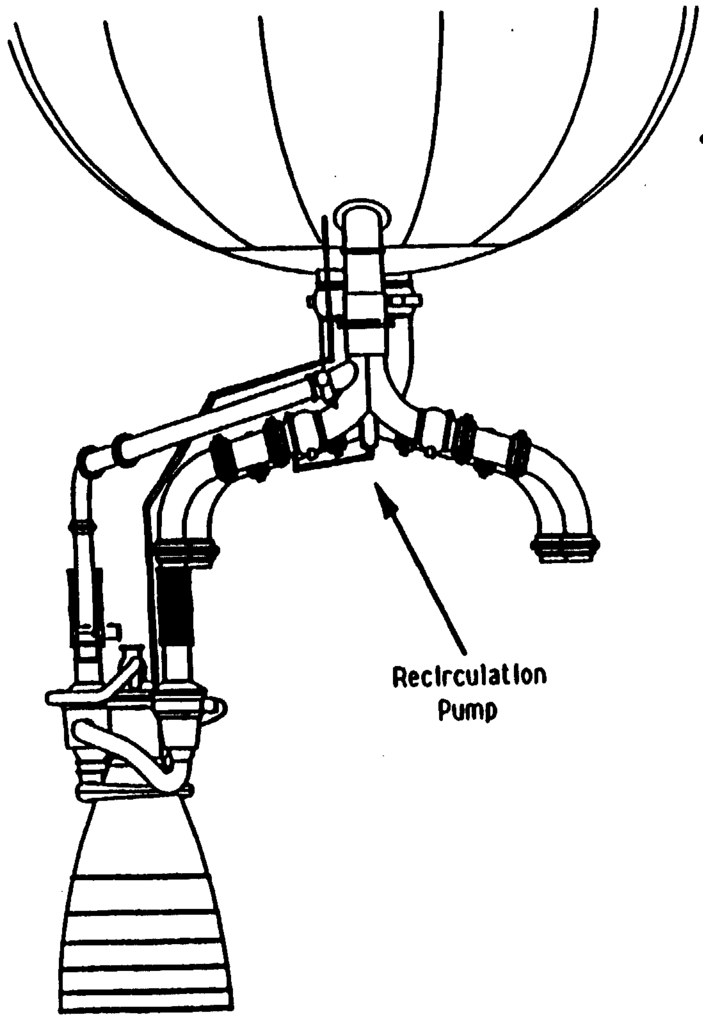
## The Forward Recirculation System

The forward recirculation system is the one used successfully on the Saturn V S-II and S-IVB Stages as well as the Shuttle. It is very predictable because of this experience, its performance is shown on the next figure for the predicted heat load and the following figure for the uninsulated turbopump, doubled heat load. The heat loads were calculated as described earlier. It is seen that this system is more sensitive to heat load than the backward recirculation system, however, this system does not put vapor into the feedline which must be condensed later during tank prepressurization. For the one degree subcooled case, with the insulated turbopump, the flowrate is one lb/sec. While the vapor volume in the exiting flow is 60% of the total volume, this is not critical because the vapor is reentering the main propellant tank. The flowrate is quite sensitive to the heat leak, unlike reverse recirculation.

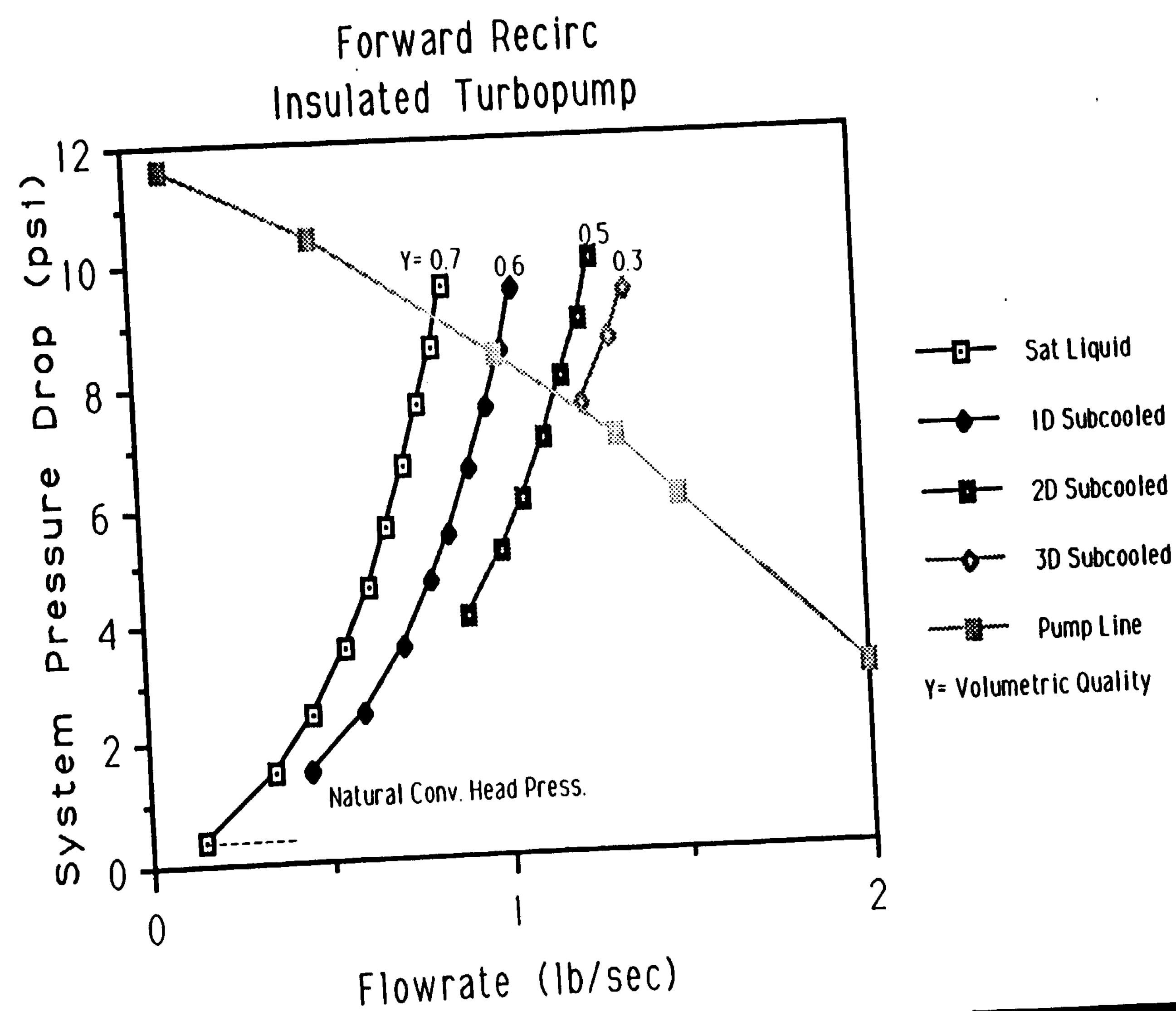
The system is considered very predictable. We have a great deal of experience with it. If the engine test facility is provided with a flight type system, and the feedlines have heat leak in the same range as flight type feedlines, repeatability from engine test to flight vehicle will be excellent. The potential for a requirement for a future change is considered small, because of the extensive experience with this system. The system in the past has had some difficulty in the operational efficiency category because of two things; connector shorts and the tendency to go into propellant loading without properly setting up the system. This should not be a problem. The hazard introduced is the potential for leaks. The hardware is relatively complex, involving small lines, pumps, valves to prevent pump spinning during powered flight, and on-board disconnects; the number of disconnects required is dependent on the design.

For predictable performance without the potential for future change requirements, the forward recirculation system is superior. The trade is between the hardware and maintenance costs of this system and the unknowns involved with any other.




## FORWARD RECIRCULATION

- STANDARD SHUTTLE RECIRC. PUMP PUMPING AROUND CLOSED PREVALVE.
  - -HYDROGEN BLEED VALVE, PROBABLY ON ENGINE GAS GENERATOR SUPPLY LINE, WILL BE REQUIRED.
  - -DISCONNECTS MUST BE PROVIDED FOR OUTBOARD LINES.
  - -RETURN CAN BE MANIFOLDED.
  - -ATTACHED CURVES SHOW MINIMUM SPECIFIED PUMP PERFORMANCE.
  - -ATTACHED CURVES SHOW SENSITIVITY TO ENGINE TURBOPUMP INSULATION AND TO HEAT LOAD OF REMAINDER OF SYSTEM.
  - -PERFORMANCE CAN BE IMPROVED BY INCREASING SYSTEM LINE DIAMETER, BUT NEED FOR GIMBALS RATHER THAN FLEX LINES MAY BE PENALTY.



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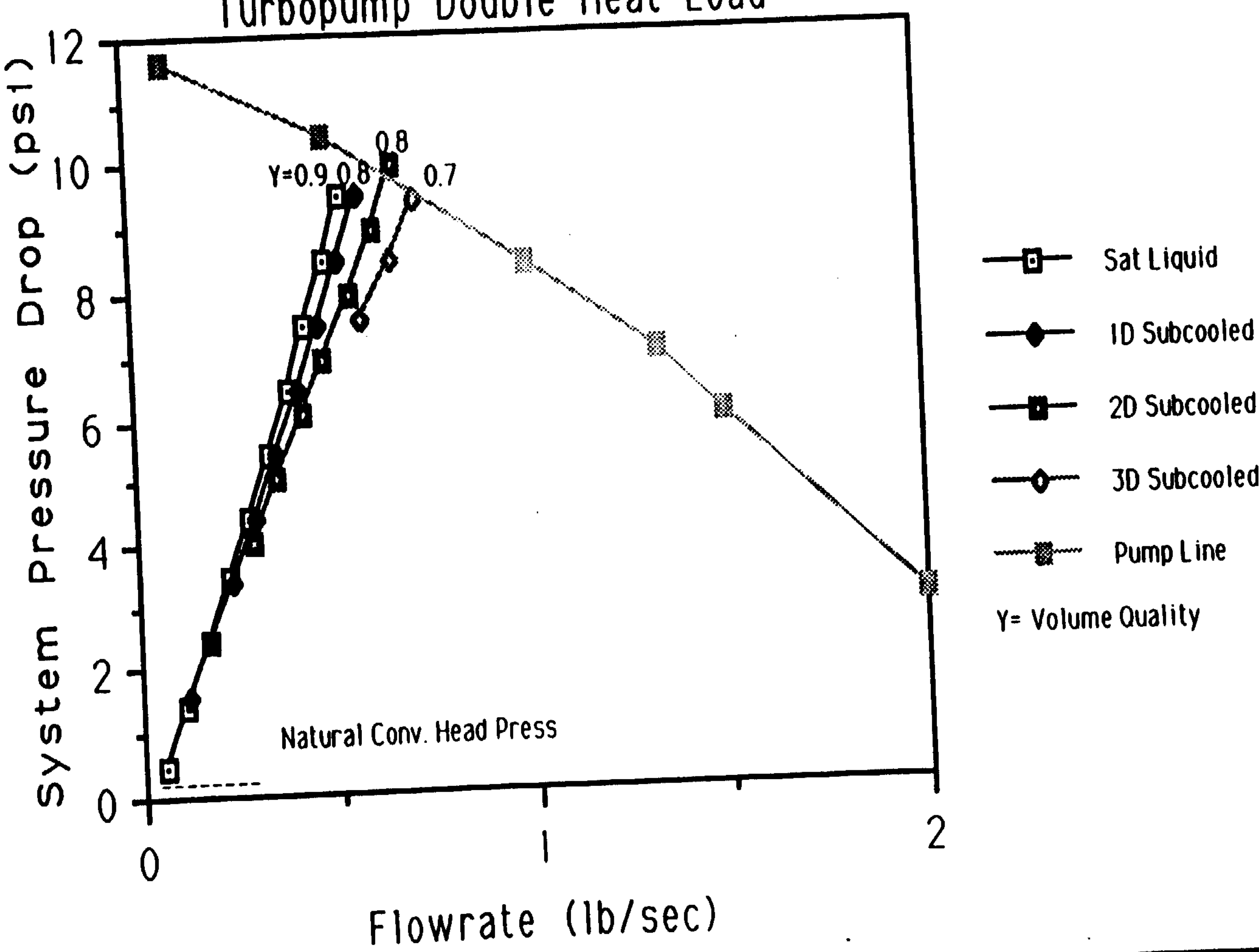
## Forward Recirc Uninsulated Turbopump Double Heat Load

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The following two figures summarize the comparison between the candidate systems. The numerical comparison reflects the verbal comparison.

# HYDROGEN FEEDLINE/ENGINE CONDITIONING

| Attributes | No Bleed | On-Board Bleed | Overboard Bleed to Facility | Backward Recirculation | Forward Recirculation |
|---|---|---|---|---|---|
| •Predictability | •Excellent | •Poor | •Poor | •Fair/Good | •Excellent |
| •Repeatability Eng. Test to Vehicle | •Poor | •Fair | •Excellent | •Fair/Good | •Good |
| •Precedence | •None | •Used on LOX on S-1 | •RL-10 On S-IV Single Engine Tests | •None | •S-II, S-IVB, Shuttle |
| •Impact on Engine Design | •None | •Adds LH2 BV | •Adds LH2 BV Potential for Turbo-pump Windmilling | •Adds LH2 BV | •Adds LH2 BV |
| •Impact on Feed System/Eng. Insulation | •Potentially Severe TP & FL Insulation Performance Reqt. | •Potentially High TP & FL Insulation Performance Reqt. | •Insensitive to TP & FL Insulation Performance | •Moderate TP & FL Insulation Performance Reqt. | •More Sensitive Than Backward Recirc. |
| •Impact on Eng. Test | •Potentially Large | •Potentially Large | •None | •Moderate | •Small |
| •Potential for Req'd Future Change | •Large | •Large | •Fairly Small | •Fairly Large | •Small |
| •Operational Efficiency | •Very Simple | •Simple - May Limit Hold After Prepress. | •May Impact Facility H2 Disposal System | •Requires Recirc. Pumps | •Requires Recirc. Pump |
| •Harzard Introduced | •None | •Low | •Adds most leak Sources | •Moderate-adds leak Sources | •Moderate - adds leak sources |
| •Hardware Complexity | •Low | •H2 BV's & Small Lines Req'd | •H2 BV's Small Lines On-Bd & Gnd Disconnects Req'd | •H2 BV's, Small Lines, Recirc. Pumps, On-Bd Disconnects Req'd | •H2 BV's, Small Lines, Recirc Pumps, Onbd Disconnects Req'd |

# LH2 FEEDLINE CONDITIONING EVALUATION MATRIX

3 - Important
2 - Somewhat Important
1 - Considered

Grades = A=4, B=3, C=2, D=1 F=0
Score = Grade · Weight

Grades/Scores

| Attributes | Weighting Factor | No Bleed | On Board Bleed | Overboard Bleed to Facility | Backward Recirculation | Forward Recirculation |
|---|---|---|---|---|---|---|
| | 2 | 4 / 8 | 1 / 2 | 1 / 2 | 2 / 4 | 4 / 8 |
| | 3 | 0 / 0 | 1 / 3 | 4 / 12 | 2 / 6 | 3 / 9 |
| Precedence | 2 | 0 / 0 | 0 / 0 | 4 / 8 | 0 / 0 | 4 / 8 |
| Impact on Eng. Design | 2 | 4 / 8 | 2 / 4 | 3 / 6 | 2 / 4 | 2 / 4 |
| Impact on Insulation | 2 | 1 / 2 | 1 / 2 | 4 / 8 | 2 / 4 | 3 / 6 |
| Impact on Eng. Test | 1 | 0 / 0 | 0 / 0 | 4 / 4 | 1 / 1 | 2 / 2 |
| Potential for Future Change | 2 | 0 / 0 | 0 / 0 | 3 / 6 | 1 / 2 | 4 / 8 |
| Operational Efficiency | 3 | 4 / 12 | 3 / 9 | 2 / 6 | 1 / 3 | 1 / 3 |
| Hazard Introduced | 3 | 4 / 12 | 3 / 9 | 0 / 0 | 2 / 6 | 2 / 6 |
| Hardware Complexity | 1 | 4 / 4 | 3 / 3 | 1 / 1 | 1 / 1 | 1 / 1 |
| Total | | 46 | 32 | 53 | 31 | 55 |

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The following tables give the hardware costs of the options, derived by a bottoms-up analysis using Martin-Marietta data. The Design, Development, Test, and Evaluation costs would be additive to these.

## LH2 Options

| Option B - LH2 Natural Convection Drive | | | | |
|---|---|---|---|---|
| **Item** | **Description** | **Qty/PM** | **Cost/Unit** | **Cost/PM** |
| Bleed Valve | Similar to SSME | 6 | 78,057 | 468,342 |
| Line | 1" ID X 6' Line W/4' Flex | 6 | 62 | 372 |
| Elbow | 1" ID 45°, R/d >= 2.5 | 6 | 10 | 61 |
| Line | 1" ID X 2' | 6 | 21 | 124 |
| Elbow | 1" ID 30°, R/d >= 2.5 | 6 | 7 | 41 |
| Line | 1" ID X 6' | 6 | 62 | 372 |
| Elbow | 1" ID 75°, R/d >= 2.5 | 6 | 17 | 101 |
| Line | 1" ID X 2' | 6 | 21 | 124 |
| Elbow | 1" ID 90°, R/d >= 2.5 | 6 | 20 | 122 |
| Check Valve | 1" Low pressure drop | 6 | 27,300 | 163,800 |
| Insulation | All flex with TPS equivalent | 6 | 804 | 4,824 |
| Insulation | All lines with 1" SOFI equiv. | 6 | 2,813 | 16,877 |
| **Total** | | | | **655,158** |

## Option C - LH2 Overboard Bleed

| Item | Description | Qty/PM | Cost/Unit | Cost/PM |
|---|---|---|---|---|
| Bleed Valve | Similar to SSME | 6 | 78,057 | 468,342 |
| Line | 1" ID X 6' Line W/4' Flex | 6 | 62 | 372 |
| Elbow | 1" ID 45°, R/d >= 2.5 | 6 | 10 | 61 |
| Line | 1" ID X 2' | 6 | 21 | 124 |
| Elbow | 1" ID 30°, R/d >= 2.5 | 6 | 7 | 41 |
| Line | 1" ID X 6' | 6 | 62 | 372 |
| Line | 1" ID X 4' (Inboard) | 6 | 41 | 248 |
| Line | 1" ID X 6' (Inboard) | 6 | 62 | 372 |
| Line | 1" ID X 10" (Inboard) | 6 | 103 | 619 |
| Tee | 1" ID (Inboard) | 6 | 100 | 600 |
| Line | 1" ID X 2' (Outbd w/out fill & drn.) | 6 | 21 | 124 |
| Disconnect | For 1" Line (Outbd. w/out f & d) | 1 | 26,000 | 26,000 |
| Line | 1" ID X 2' (Outbd w/out f & d) | 6 | 21 | 124 |
| Elbow | 1" ID 90°, R/d >= 2.5 (Outbd w/out fill & drain) | 6 | 20 | 122 |
| Line | 1" ID X 8' (Outbd w/fill & drain) | 6 | 246 | 1,473 |
| Elbow | 2" ID 90°, R/d >= 2.5 (Outbd w/fill & drain) | 6 | 120 | 723 |
| Line | 2" ID X 6' (Outbd w/fill & drain) | 6 | 184 | 1,105 |
| Elbow | 2" ID X 90°, R/d >= 2.5 (Outbd w/f & d) | 6 | 120 | 723 |
| Disconnect | 1.5" ID Vehicle/Ground | 1 | 26,000 | 26,000 |
| Line | 1.5" ID X 12' (Across tank bottom) | 6 | 234 | 1,405 |
| Tee | 12.5" X 1 | 12 | 150 | 1,800 |
| Disconnect | 1.5" | 1 | 26,000 | 25,000 |
| Tee | 2.5" | 6 | 250 | 1,500 |
| Insulation | All flex with TPS equivalent | 6 | 804 | 4,824 |
| Insulation | Al lines with 1" SOFI or equiv. | 6 | 11,251 | 67,507 |
| Total | | | | 630,578 |



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| Option D - LH2 Forward Recirculation | | | | |
|---|---|---|---|---|
| **Item** | **Description** | **Qty/PM** | **Cost/Unit** | **Cost/PM** |
| Recirculation Pump | Same as STS(MC281-0030-0002) | 6 | 137,500 | 825,000 |
| Shutoff Valve | 1" dia equiv flow area (MC284-0395-0051) | 6 | 75,125 | 450,750 |
| Elbow | 1" ID, R/d >= 2.5 | 6 | 20 | 122 |
| Line | 1" ID X 3' Line Flex | 6 | 31 | 186 |
| Elbow | 1" ID, R/d >= 2.5 (to d/stream end of prevalve) | 6 | 20 | 122 |
| Bleed Valve | Similar to SSME | 6 | 78,057 | 468,342 |
| Line | 1.125" ID X 6" Line W/3'Flex (gimballing capable) | 6 | 78 | 450 |
| Elbow | 1.125" ID 75°, R/d>= 2.5 | 6 | 23 | 138 |
| Line | 1.125" ID X 7' Line | 6 | 88 | 525 |
| Elbow | 1.125" ID 75°, r/d >= 2.5 | 6 | 23 | 138 |
| Line | 1.125" ID X 5' Line | 6 | 63 | 375 |
| Elbow | 1.125" ID 75°, R/d >= 2.5 | 6 | 23 | 138 |
| Inlet Fitting | To Tank Bottom | 1 | 8,000 | 8,000 |
| Manifold | 4 to 1 | 1 | 10,000 | 10,000 |
| Manifold | 2 to 1 | 1 | 10,000 | 10,000 |
| Insulation | All lines with 1" SOFI or equiv. | 6 | 3,692 | 22,151 |
| **Total** | | | | **1,796,437** |



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| Option F - LH2 Backward Recirculation | | | | |
|---|---|---|---|---|
| Item | Description | Qty/PM | Cost/Unit | Cost/PM |
| Recirculation Pump | Same as STS (MC281-0030-0002) | 6 | 137,500 | 825,000 |
| Shutoff Valve | 1" dia equiv flow area (MC284-0395-0051) | 6 | 75,125 | 450,750 |
| Disconnect | For 1" Lines | 6 | 26,000 | 156,000 |
| Line | 1" ID X 6' | 6 | 62 | 372 |
| Line | 1" ID X 7' | 6 | 72 | 433 |
| Line | 1" ID X 4' | 6 | 41 | 248 |
| Line | 1" ID X 3' | 6 | 31 | 186 |
| Bleed Valve | Similar to SSME | 6 | 78,057 | 466,342 |
| Insulation | All lines with 1" SOFI or equiv. | 6 | 4,219 | 25,315 |
| **Total** | | | | **1,924,646** |

## Task 3-P-034 Addendum

| Weight Estimates | lb. |
|---|---|
| • On-Board LH2 Bleed (Option B - LH2 Natural Conv. Driven) | 93 |
| • LH2 Overboard Bleed (Option C) | 255 |
| • LH2 Forward Recirculation (Option D ) | 331 |
| • LH2 Backward Recirculation (Option F) | 328 |

## Summary & Conclusions

- Reference No-Bleed System will result in saturated $LH_2$ in feedline and engine pump with vapor in engine pump and dry lines downstream of engine pump.
  Convection path complicated by screen.
  Analytical model and test program to anchor analytical model required.
  Warm-up after prepressurization increases saturation pressure 5 psi/minute.
  Would require depressurization of tank, repressurization for very short hold.
  (Engine start pressure not yet defined.)
- On-Board Bleed has low flowrate, hydrogen quality in turbopump will be poor (80% vapor by volume). If this is satisfactory, would allow improvement in hold after prepress relative to no-bleed system.
  Test program required.
  Slight improvement in performance compared to no bleed.
- Overboard bleed has adequate performance after prepressurization. Hold time limited due to loss of $LH_2$ at 1.2 lb/sec per engine.
  Hardware complexity a disadvantage.
  SSME manufacturer uses this system, in principle, for single engine tests.
  Should be retained for further study.
- Backward recirculation did not appear advantageous.
  Provides good engine/pump chill.
  Introduces large volume of vapor into feedlines.
  Hardware complexity a disadvantage.
- Forward recirculation:
  Predictable, good experience with systems.
  Hardware complexity a disadvantage.
  Together with overboard bleed, provides best engine/pump chill.
  Provides best performance (best chill, no hold time limitation).

# Task Number 3-P-038

# LH2 Tank Pressure Limits

Prepared By:
D. Vaughan
20 Dec, 1991

Approved By:
Z. Kirkland

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## Executive Summary

NASA Statement of Work:

"Establish $LH_2$ tank pressure limits vs. flight time considering engine start and NPSP requirements, potential pressure stabilization of tank during max airloads, structural weight considering proof test requirements and performance. Also consider ascent venting criteria."

- Current autogenous flowrate results in high tank pressures that will set the vent valve relief setting at ~60 psig.
- Structural impact of ~7000 lbm due to high tank pressures. Pressure can be reduced with decreased autogenous flowrate. Proposed flowrates of 1.1 lbm/sec/booster and 0.9 lbm/sec/sustainer still results in ~1500 lbm payload impact.
- NPSP consideration indicate that the minimum ullage pressure to satisfy NPSP requirements will be ~31 psig @ MECO.
- To reduce further the structural impact an alternate pressurization system will be required, i.e., flow control valves, step orifice control.

**Task Number 3-P-038**
**LH2 Tank Pressure Limits**

## 1.0 Summary

Baseline system results in very high tank pressure during ascent. Tank impact is ~7000 lbm. This can be reduced by selecting booster and sustainer pressurization flowrates of 1.0 lbm/sec. The tank impact is then reduced to ~1500 lbm.

NPSP requirements set the lower pressure requirement at ~31 psia.

## 2.0 Problem

Assess LH2 tank pressure limits.

## 3.0 Objective

Determine tank and system impacts for the reference configuration.

## 4.0 Approach

The approach to performing this study was:

- To generate ullage pressure vs. time for the reference configuration and assess system impacts.
- Develop system to minimize impacts to the tank and still maintain adequate NPSP margin.

## 5.0 Results

The results of this study are attached. The main results of the study are listed below.

## 6.0 Conclusions and Recommendations

The baseline autogenous flowrate of 1.4 lbm/sec results in high tank pressures that impact the tank structure by ~7000 lbm and maintain ample margin for NPSP requirements. Reduction of the autogenous flowrate to 1.0 lbm/sec reduces the impact to the tank structure to ~1500 lbm and provides adequate NPSP.

## 7.0 Supporting Data

## 8.0 Attachments

Study "Task Number 3-P-025, LO2 Tank Pressure Limits," dated 12/20/91.

# Task Number 3-P-038

# LH2 Tank Pressure Limits

# Attachment-Detailed Data

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## Approach

Generate baseline ullage pressure for HLLV and 1.5 Stage

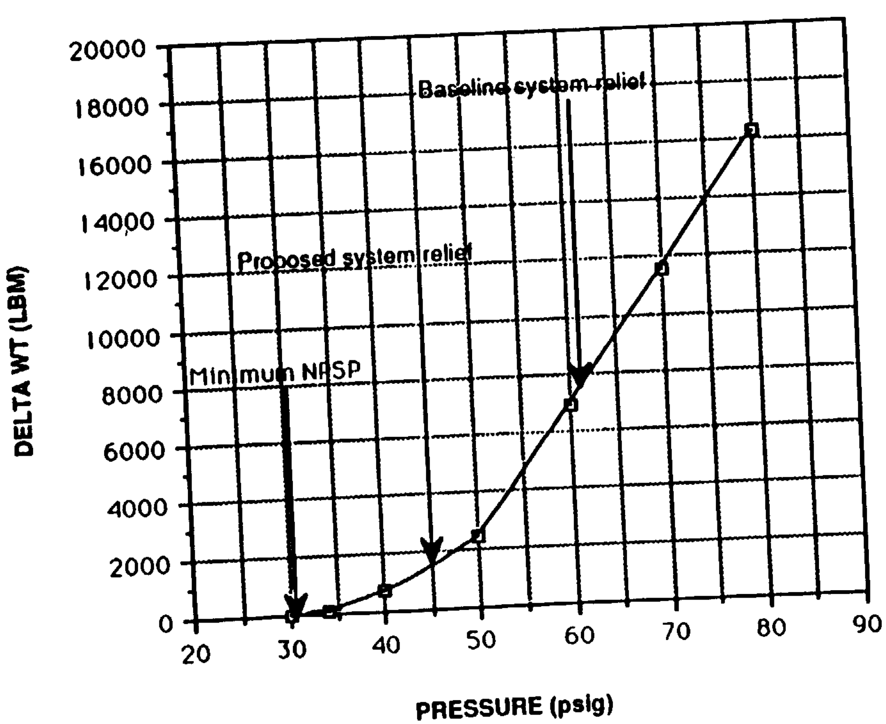
Generate issues with system and structural impact

Trade residuals with engine NPSP requirements and engine cost sensitivities

# RESULTS

- Baseline autogenous system results in high(60 psig) ullage pressures. Structural evaluation shows this to be ~ 7000 lbm payload impact

LH2 Tank Weight Impact



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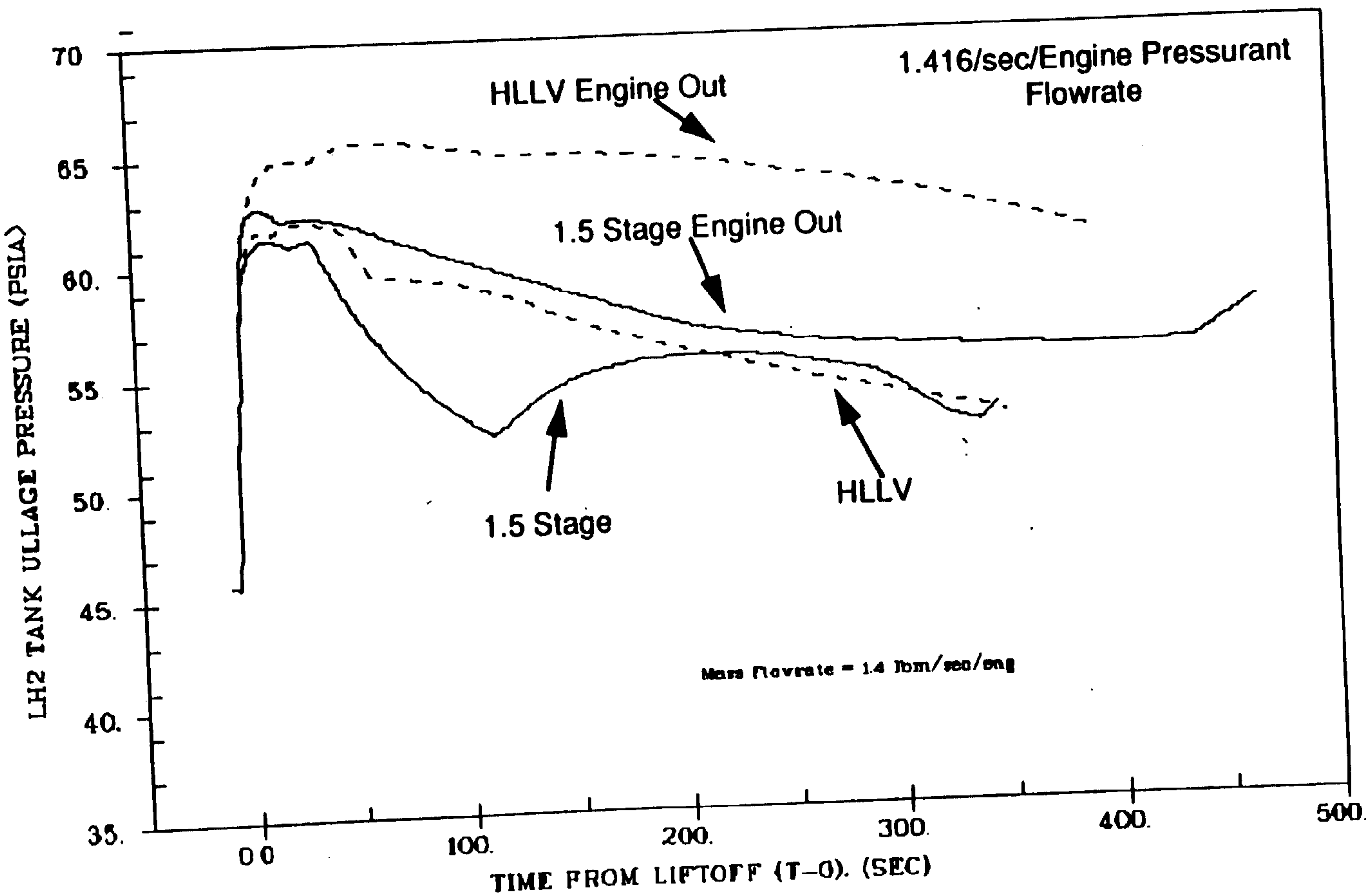
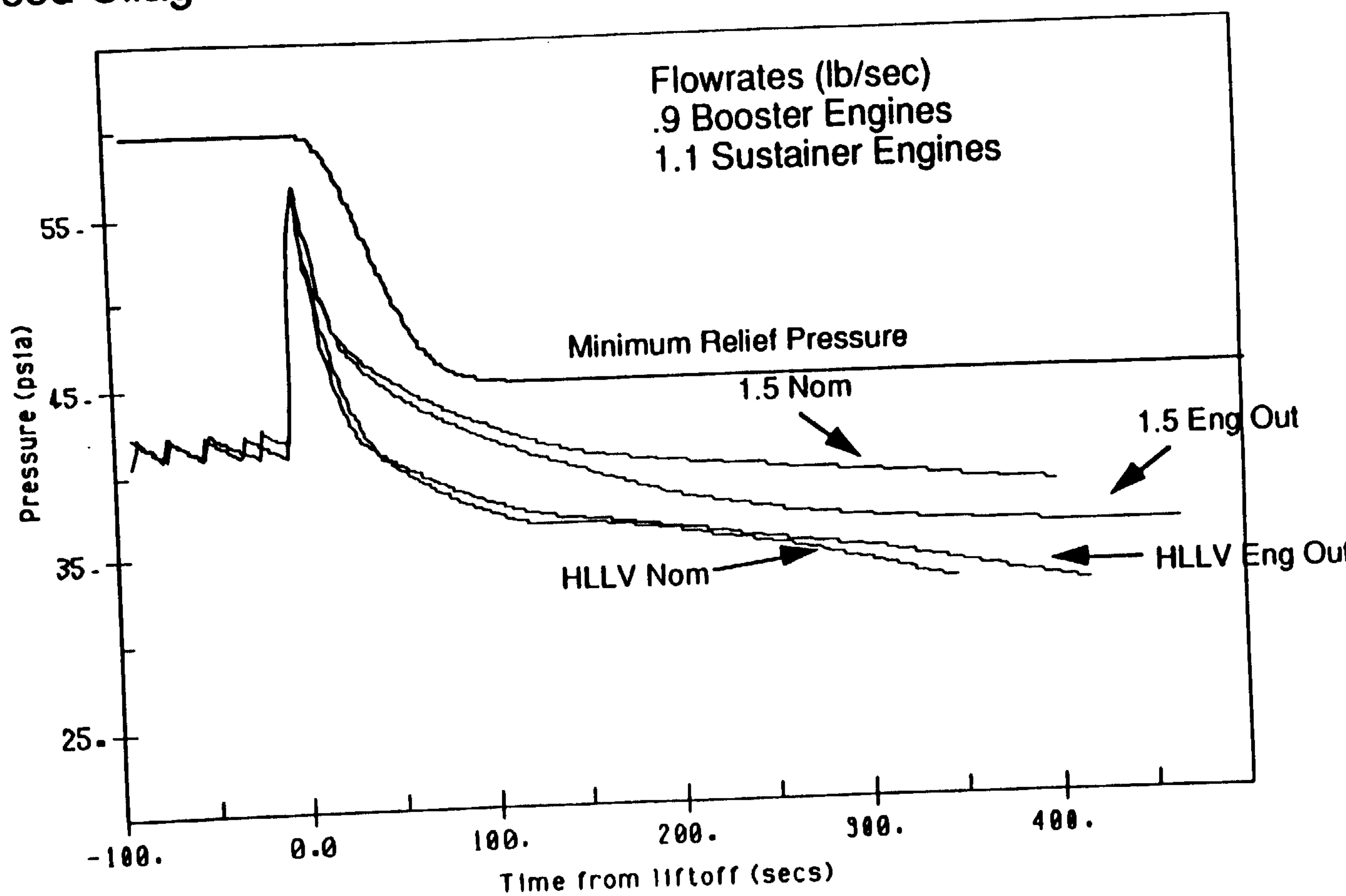
# Baseline Ullage Pressure



## Results

- NPSP results generated by RI indicated a minimum ullage pressure of ~36 psig. This analysis did not take into consideration the benefit of throttling on NPSP requirement. This reduces the NPSP requirement from 13.1 to 7.6 psi. This effect lowers the minimum ullage pressure to ~31 psig.
- To reduce the structural impact the autogenous flowrate can be orificed to minimize this impact while still providing adequate NPSP margin. The proposed flowrates are 1.1 lbm/sec/booster engine and 0.9 lbm/sec/sustainer engine. This still results in a payload impact of ~1500 lbm.

## Proposed Ullage Pressure



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## Summary & Conclusions

- Current autogenous flowrate results in high tank pressures that will set the vent valve relief setting at ~60 psig.
- Structural impact of ~7000 lbm due to high tank pressures. Pressure can be reduced with decreased autogenous flowrate. Proposed flowrates of 1.1 lbm/sec/booster and 0.9 lbm/sec/sustainer still results in ~1500 lbm payload impact.
- NPSP consideration indicate that the minimum ullage pressure to satisfy NPSP requirements will be ~31 psig @ MECO.
- To reduce further the structural impact an alternate pressurization system will be required, i.e., flow control valves, step orifice control.

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# Task Number 3-P-039

# LH2 Pressurization System

20 Dec, 1991

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# Executive Summary

**NASA Statement of Work:**

"Select optimum LH2 tank pressurization system based on tank pressure limits and specified reference trajectories and considering safety, reliability,operability, simplicity, weight, including residuals, and cost."

**Approach:**

Generate baseline pressure profiles for HLLV and 1.5 Stage

Generate issues and concerns to reference

Evaluate reference with structural and NPSP requirements

Generate alternate approaches

**Results:**

1) Baseline fixed orifice system results in high ullage pressures during flight that have a substantial structural weight impact. NPSP requirements are only ~31 psig which results in too much margin.
2) Structural weight impact can be reduced by reduction in fixed orifice flowrate to ~1.0 lbm/sec/engine. This still results in ~1500 lbm impact due to the high ullage pressure that exists during the first portion of the flight.
3) Two approaches have been examined to reduce the initial tank pressure without impacting the NPSP requirement. These are a flow control system and a step pressurization system.
4) Assisted customer in set-up and analysis of pressurization systems.

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# 3-P-039 LH2 Pressurization System

**Background**

Martin Marietta Manned Space Systems was initially assigned performance of the subject contract task at the beginning of cycle 0. Early task planning was completed and preliminary analysis was done, after which the Propulsion Working Group made the decision to complete this task in-house. Martin Marietta continued to participate in the task in a review and advisory role.

This report documents the planning and analysis work performed by Martin Marietta and includes a summary of the results provided to MSFC for their completion of this task.

The following 3 pages document the task planning effort for the LH2 Pressurization System Study.

# 3-P-039
# LH2 Tank Pressurization System

"Select LH2 tank pressurization system (based on pressure limits from 3-P-038) and specified reference trajectories, and considering safety, reliability, operability, simplicity, possible integration with the core RCS system, weight including residuals, and cost."

## Work Statement

The unquestionable advantages of using warm hydrogen gas to pressurize the LH2 tank and the potential use of hydrogen gas as a roll control propellant reduce this study to one of evaluating the advantages of warmer hydrogen as a pressurant, the possibility of obtaining warmer hydrogen from the STME, a control system evaluation, and evaluation of the pressurant diffuser for this system. The study should consider the flow within the pressurant lines and diffuser for both 1 1/2 stage and HLLV, and the manifolding configuration to allow use of hydrogen for roll control.

Compute tank wall temperatures and pressurant weights for pressurant temperatures of 0, 100, and 200 °F. In task 3-P-038, evaluate tank pressure capability for increased tank wall temperature. With the STME project, evaluate the feasibility of obtaining higher temperature pressurant from the STME. Obtain control impulse requirements from vehicle dynamics studies 3-FM-028 "Generate FCS Requirements." Compare required impulse with impulse available from hydrogen bled from pressurization system. Evaluate reliability effects of this increased control system complexity. Compute flow parameters of pressurant lines and pressurant diffuser and attitude control manifolds. Compute system cost and compare with independent reaction control system (RCS) cost.

## Input Data

Control impulse requirements from 3-FM-028 "Generate FCS Requirements."

Engine characteristics regarding bleed flow temperatures available.

LH2 tank pressure limits data from task 3-P-038.

Tank wall temperature model from MMC-Operations (D. Vaughn).

Tank wall heat fluxes from task 3-FM-005.

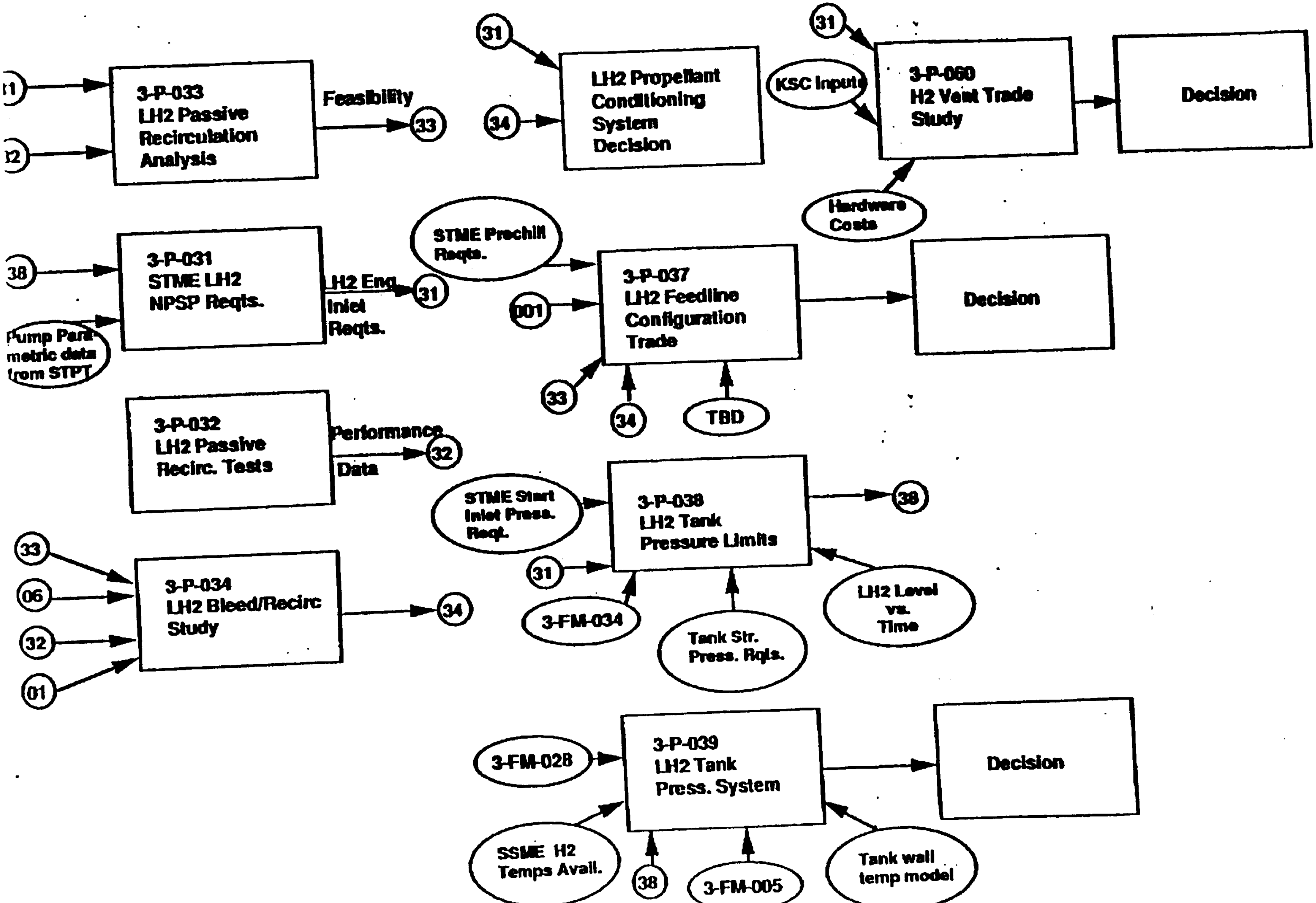
## Products

Study results showing advantages/disadvantages of pressurant temperatures form 0-200 °F.

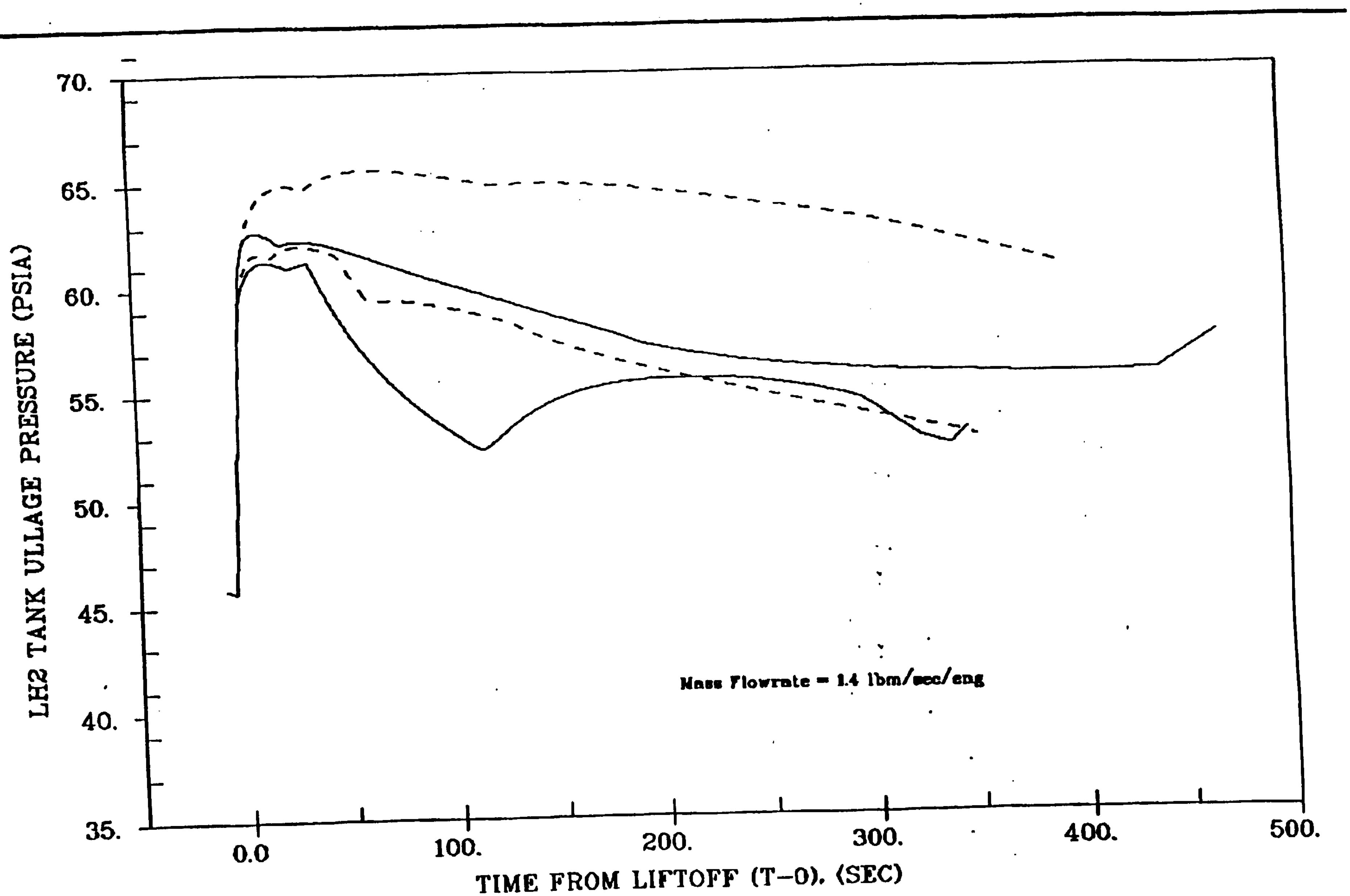
Evaluation of use of H2 for attitude control vs. separate RCS with regard to advantages/disadvantages, reliability, operability, cost.

Line size and manifolding requirements for pressurization/RCS system.

BOATTAIL/PROPULSION ᴾT DEFINITION



**This figure (LH2 Tank Ullage Pressure vs. Time from Liftoff) is a preliminary analysis of LH2 Tank pressure profile for the reference trajectory.**

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